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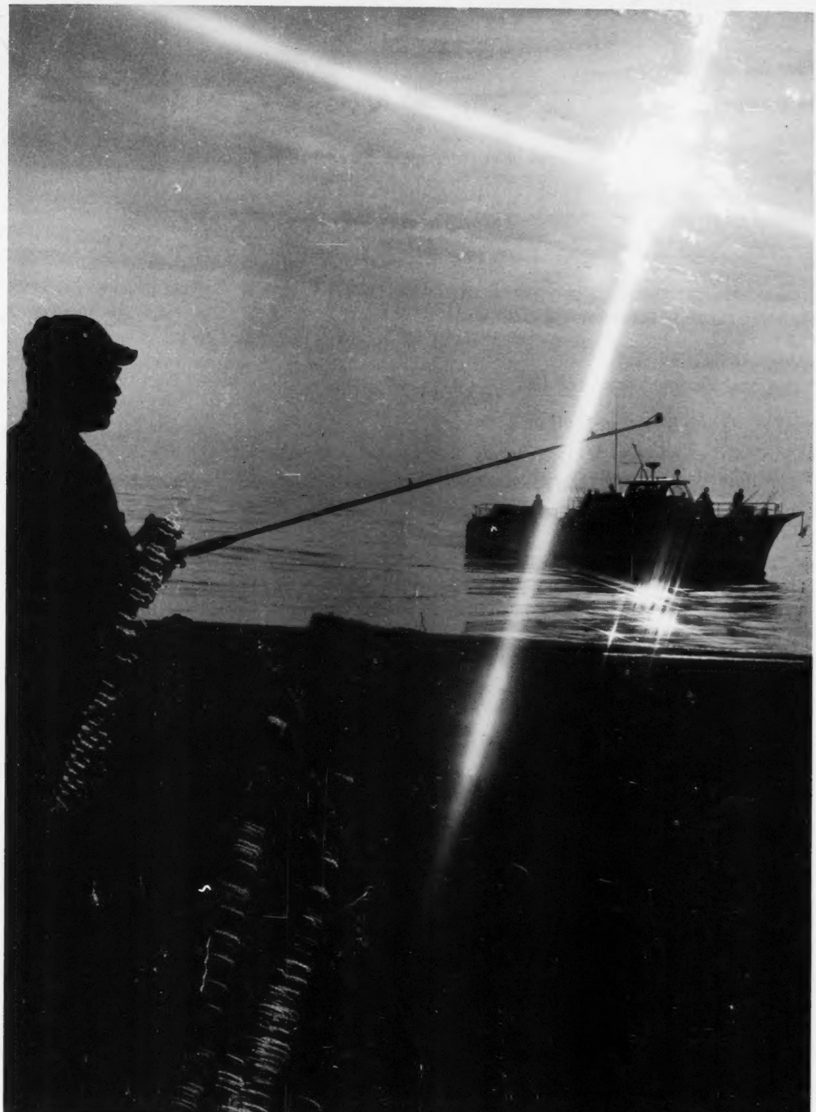

Marine Angling

Marine Fisheries REVIEW

Marine recreational angling. Florida News Bureau photo by Jack Fortune.

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A Review of Introductions of Exotic Oysters and Biological Planning for New Importations

JAY D. ANDREWS

ABSTRACT—Importation and transplantation of exotic oysters has probably resulted in the introduction into new areas of more marine invertebrate species than any other of man's activities. Unintentional introductions have resulted from careless movements of oysters without planning or consideration of consequences. Diseases and parasites of marine invertebrates are poorly known and oysters cannot be adequately diagnosed or inspected for problems by biologists. The vigorous Pacific oyster, Crassostrea gigas, *was introduced to the Atlantic coast of western Europe in the past decade with serious effects on native oyster species. Some scientists propose to introduce it to the Atlantic coast of North America, primarily for culture in New England. If introduction is carried out properly, diseases and parasites may be excluded by breeding selected brood oysters in hatcheries under quarantine conditions. The progeny may then be tested in controlled natural environments for growth rates and reaction to native diseases and parasites. Selection of races, strains, and hybrids may be pursued in hatcheries to fit exotic oysters to new ecosystems. Introduction of an exotic species is a serious irreversible event which merits careful consideration of the reasons for culture of a new shellfish and the consequences to native biota and coastal ecosystems.*

Introduction

Oysters have been transported by mankind since Roman times because they are superbly adapted to withstand long journeys out of water. In this paper, the consequences of man's movement of oysters and the biological requirements for future introductions of oysters are reviewed.

Only one species of oyster, *Crassostrea gigas*, the Pacific oyster, has been introduced as a successful member of coastal communities around the world. In the temperate zone of the Northern Hemisphere only the Atlantic coast of North America does not now depend on this species for oyster production. *Crassostrea gigas* was successfully introduced to western North America, western European, and Australasian coasts. Most introductions began as casual unplanned events that were soon followed by deliberate ones on a larger scale. With the aid of man, the oysters spread on the coasts to the limit of their tolerances of climates and salinities.

Some scientists desire to culture *C. gigas* in New England. A major problem is keeping it confined to New England and away from large oyster fisheries of *C. virginica* to the south. *Crassostrea gigas* is a vigorous, fast-growing oyster that could compete advantageously with the native oyster, and possibly replace it, in the warm waters of Chesapeake Bay and Delaware Bay.

The famous European flat oyster, *Ostrea edulis*, has been tried on both coasts of North America and in Japanese waters with little success as a self-sustaining species. It is frequently grown in hatcheries in North America for experimental plantings. This favorite raw-bar oyster sustains a small industry in Maine by use of hatchery seed from acclimated broodstocks precariously established in Boothbay Harbor, Maine (Welch, 1966).

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Extensive transplantation of native oysters along major coasts has long been used to sustain fisheries without regard for adaptations of local races to new environments. Transplantation of flat oysters from one country to another in Europe has a long history. It was instigated primarily because of failure of reproduction in the cold waters of northern countries such as France, Great Britain, the Netherlands, and Denmark (ICES, 1972). Crises such as continent-wide unexplained mortalities in 1920-21 and recent (1967-76) mortalities from diseases also caused extensive importations from the Adriatic Sea and Greece as well as Spain and Portugal. No consideration was given to racial traits of these diverse stocks for adaptation to various local climates (Andrews, 1979b). However, the Netherlands is trying to build up stocks of isolated native oysters which exhibit greater winter hardiness than imported French seed oysters now sustaining the industry (Drinkwaard, 1978). Transplantation between regions on a coast is a short-term marketing expedient that is not expected to contribute to rehabilitation of native stocks. However, it may result in genetic mixing and the spread of pests and diseases.

The impact of exotic marine species on endemic communities is difficult to predict until they are widespread in the new area and irrevocably established. Introductions of marine exotics are more difficult to isolate and to control than terrestrial ones because of rapid dispersion of larvae by currents.

Inadequate monitoring and limited knowledge of identity, abundance, and distribution of native species may leave exotic species obscured for long periods. Often diseases of marine invertebrates become known only after mass mortalities of the host species (Sindermann, 1976). Seldom can such diseases be proven to be introduced. The strongest circumstantial evidence is that of timing when stocks were transplanted or imported immediately before an epizootic mortality.

Categories of Importations

The transport of endemic oysters of the same species along a coast is defined as transplantation (Mann, 1979). This is not the primary concern of this discussion. After hundreds of years of transplantation the potential for further damage may be minimal. However, care should be exercised in moving endemic oysters from regions of a coast that have been isolated by land barriers, ocean currents, or even temperature differences for many centuries. Exchanges between such areas on a coast carry the same dangers from diseases and pests as from importation of exotic oysters of a different species. Examples of isolated regions in North America include the Gulf of Mexico and the Gulf of St. Lawrence from which transplantings to and from the Middle Atlantic coast have been rare. The Mediterranean Sea and the Atlantic coast of Europe could also be hazardous regions for exchanges of oysters.

Importations of exotic species of oysters that result in establishment of new populations are called introductions to distinguish them from transplantations along a coast. Introductions from one continental coast to another are nearly always through the activities and agencies of man because wide land or ocean barriers preclude natural dispersal. These importations may be deliberate or accidental depending upon the role of man. They can be subdivided into several categories according to the purpose of the importation, agent of dispersal, and stage of the organism utilized (ICES, 1972). For purposes of discussion, casual importations of small lots of oysters without planning, supervision, or subsequent monitoring may be considered accidental. The risks and consequences are the same as for strictly accidental importations, i.e., inadvertent introductions. Most large-scale importations of oysters were preceded by accidental ones on a small scale. These accidental importations may prepare the way sociologically for subsequent large-scale deliberate ones. Imported oysters may exhibit excellent growth and survival while native species are destroyed by exotic diseases associated with the importation. This series of events occurred recently in France following importation of *C. gigas* in 1966 (Marteil, 1976).

Adaptations of Marine Organisms to Oceanic and Continental Climates

Continental air masses crossing large land masses exhibit the rapid heating and cooling attributes of the land with strong warming during summers and prolonged cooling from back-radiation in winters. Coastal waters on the eastern shores of continents share these extremes of atmospheric temperature with cold winter and warm summer temperatures. In contrast, coastal waters on western shores of continents, bathed by moderated oceanic air masses, receive mild weather, therefore, exhibit cool summers and mild winters. Hydroclimographs for estuaries on the eastern coast of North America show annual temperature ranges of 20°C or more inshore, whereas those for the western coast exhibit only about 10°C range (Andrews, 1971). These differences in maximal and minimal mean temperatures affect adaptations for summer breeding and winter survival of endemic species on the respective coasts.

The temperature effects on imported exotic species are most dramatic on maritime coasts which receive ocean-tempered air masses and currents that induce summer upwelling of deep, cold waters. The resulting moderated water temperatures and nutrient enrichment from upwelling ensure rapid growth in a continuous growing season for most organisms. Marine species native to continental-type climates with wide distributions and northern ranges are most likely to establish populations on coasts with oceanic climates. In contrast, organisms acclimated to mild oceanic climates are usually not able to survive either summer or winter extremes in severe climates of continental-type coasts. These adaptations to climates explain in large measure the numerous invasions of exotic species in the temperate zones on the western coasts of continents (Hanna, 1966) whereas introduced species are rare on eastern coasts. Tropical coasts are more easily invaded (Courtenay and Robins, 1973).

In general, *Ostrea* species are adapted to oceanic climates and *Crassostrea* to continental ones, although exceptions occur as waters along a coast become more tropical. Consequently, *Ostrea* species breed at lower summer temperatures (usually $<20°C$) and are more sensitive to low salinities and low winter temperatures. They will not withstand intertidal exposure to heat or cold. *Ostrea edulis* and *O. lurida* are the endemic species of western Europe and western North America, respectively; *Crassostrea virginica* and *C. gigas* are respective endemic commercial oysters of eastern shores of North America and Asia. These adaptations to respective climates should be considered before irreversible consequences of importations are incurred. Examples of serious alterations of biotic communities by importations of exotic oysters with their associated faunas are found on the maritime coasts of western Europe and western North America (Quayle, 1964; Hanna, 1966; Dundee, 1969; ICES, 1972).

Brief History of Major Introductions of Oysters

Crassostrea angulata From Portugal and Spain to France

Crassostrea angulata, the Portuguese oyster, is known to have thrived in southwestern Portugal and southern Spain for several hundred years (Korringa, 1970). The Sado and Tejo Rivers and the Gulf of Cadiz provide waters warm enough ($>20°C$) for reproduction of this subtropical oyster. The oysters were little used locally. When the natural public beds of *O. edulis* in southwest France and northern Spain were depleted about 1850, a famous

report by Costé (1861) to Napoleon III initiated private culture. With a scarcity of *O. edulis* seed stocks, *C. angulata* was soon imported from Portugal's Sado River to stock private beds. The initial introduction of *C. angulata* to the French coast was attributed to the dumping of a shipload of spoiling oysters in the Gironde River in 1868 (Marteil, 1976). *Crassostrea angulata* proliferated in the Gironde and other areas of southwest France providing seed stocks for a hundred years. Eventually, in the 1960's, it produced five times as many oysters in France as *O. edulis* (Marteil, 1970). Cold summer temperatures prevented the Portuguese oyster from reproducing in Brittany and more northern countries; therefore it was transplanted annually to Great Britain for growth and marketing.

Although *C. angulata* was considered to have a less desirable taste than the European flat oyster, it provided in abundance relatively inexpensive oysters for Europe. It was a useful introduction to supplement production of the more temperature-sensitive *O. edulis* which is slower and more difficult to grow. The Portuguese oyster often sets and grows intertidally which offers cultural advantages of pest control and intensive visual farming at low tides. It is difficult to judge the extent of biological competition in France because *O. edulis* was grown primarily in Brittany and was overfished and depleted in southwest France before *C. angulata* was introduced. The Portuguese oyster certainly replaced the flat oyster in the warm waters of southern France where the latter was native.

Crassostrea gigas From Japan to France (1966)

A small importation of 900 kg of seed of the Pacific oyster was introduced to the Marennes area of France in March 1966 (ICES, 1972). The following fall (November 1966), a new disease was found in the gills of *C. angulata* by Trochon (Marteil, 1969, 1976). The disease spread widely in France and in the fall of 1967 an embargo was placed on further importations from Japan. However, the rapid decline in production of the Portuguese oyster from mortalities caused by the gill disease resulted in a decision to import *C. gigas* in commercial quantities in the early 1970's. In southwestern France, *C. gigas* reproduced prolifically permitting the cessation of commercial importations after 1975.

Another disease appeared in *O. edulis* in Brittany in Aber Wrach in 1968 where some Pacific oysters were being held. Aber Disease, caused by a protozoan, *Marteilia refringens*, caused extensive mortalities of flat oysters in Brittany. *Crassostrea gigas* was not appreciably affected by either of the new diseases. A shell malady of *C. gigas* has affected marketing somewhat (Marteil, 1976). *Crassostrea gigas* has completely replaced *C. angulata* in French waters south of Brittany and it has tended to breed farther north in Brittany and in the Netherlands in warm summers such as 1976 (23°C). Intensive spatfalls through 1976 in southern France reduced the growth rate by crowding.

Crassostrea virginica (1869) and *C. gigas* (1902) to Pacific Coast of North America

The native Olympia oyster, *Ostrea lurida*, of this coast is small, slow-growing, and difficult to culture (Korringa, 1976). Overfishing of natural beds caused depletion of most areas in the last half of the 19th century. A further decline occurred in the mid-1920's despite adoption of European cultural methods of diked parks to protect the cold- and heat-sensitive Olympia oysters from exposure to air temperatures. From 1928 to 1945, pulpmill wastes were blamed for the decline in southern Puget Sound (McKernan et al., 1949). The species did not recover production appreciably after the pulpmill was closed. Oyster planters turned their attention to *C. gigas* in the late 1920's. This species grew to marketable size in 2 years from imported Japanese seed whereas the Olympia oyster required about 4 years to attain its maximum size of 2 inches. *Ostrea lurida* did not fulfill the needs of a region with rich waters suitable for extensive oyster culture.

The first importations of the eastern oyster, *C. virginica*, began about 1869 to San Francisco Bay with completion of transcontinental railroads (Hanna, 1966). Shipments of oysters from New England continued to various rail points along the coast until about 1935. Growth was excellent in the early years but failure of reproduction from low summer temperatures required regular importations from the east coast. *Crassostrea virginica* is now rare on the Pacific Coast with one small persistent population in Boundary Bay, B.C. (Bourne, 1979). Importations over a period of 60 years failed to establish the species. The cool California current and accompanying upwelling kept coastal waters too cold for regular reproduction. Nevertheless, California permitted regular importation and planting of market-sized oysters from Long Island for raw-bar trade in the 1960's and 1970's. During this period, risks were high of introduction of new diseases prevalent on the east coast.

Crassostrea gigas has supported a growing industry along wide reaches of the Pacific Coast. The earliest importations were made by oriental residents about 1902 (Kincaid, 1951). Beginning in the late 1920's thousands of cases of spat on shells were shipped from Japan on decks of ships (Quayle, 1964). High prices and competition with air shipments to France greatly reduced Pacific Coast importations from Japan in the early 1970's. Fortunately, the industry has developed its own seed supply over the years. Two areas of regular spatfalls, Pendrell Sound, B.C., and Dabob Bay, Wash., supplement seed supplies for growing areas with irregular or no sets (Quayle, 1969; Bourne, 1979).

Crassostrea gigas From Japan to Australasia (1947-52)

Crassostrea gigas became established in Tasmania about 25 years ago. Five shipments from Japan to Australia were made between 1947 and 1952 (Thomson, 1952, 1959; Bourne, 1979). Three races of Pacific oysters (Miyagi, Kumamoto, and Hiroshima) were shipped as spat on shells and planted at two sites. Oysters planted at Pittwater on the southern shore of Tasmania survived well. Those exposed on the shores of southern West Australia died.

One recent shipment (1970) from Japan concluded the importations (Medcof and Wolf, 1975). Transplantations from Pittwater were made to Pt. Sorell on the northern shore of Tasmania where the species is now firmly established. Relative isolation at Pittwater provided a period for observation of growth and mortalities before native oysters were exposed. Unfortunately, all three races were planted in the same area and the surviving race of acclimated oysters is not known—probably Miyagi or Hiroshima oysters or a mixture.

Scattered individuals of *C. gigas* appeared in New South Wales in the 1970's where an important commercial fishery for *C. commercialis* is pursued (Medcof and Wolf, 1975). Some specimens were found on cultch sticks used to collect native oysters, implying that they were derived from larvae originating in the locality. The Pacific oyster outgrew the native oyster on these sticks suggesting that environmental conditions are favorable for growth. The location and source of brood oysters for spat found in New South Wales are unknown but probably they were derived from small accidental or illegal importations from Tasmania. Dispersal has been slow in Australasia providing opportunities to monitor population increases, and permitting industry adaptations if *C. gigas* replaces the native rock oysters. Four Australian states permit transplantings of *C. gigas* whereas New South Wales, with a valuable fishery based on *C. commercialis*, does not. *Crassostrea gigas* appeared suddenly in New Zealand in 1970 from unknown sources (Dinamani, 1974) and is increasing rapidly in abundance. Further spread of *C. gigas* in temperate zones of Australasia is to be expected.

Introduction of Exotic Invertebrate Species Associated With Oysters

Exotic Invertebrate Species in Western European Waters

The most serious introductions of foreign species accompanied importation of American oysters, *C. virginica*, to Great Britain. Reproduction did not occur in the cold waters, therefore they were relaid in British waters annually from the late 1800's to 1939 for growth and marketing (ICES, 1972). Among the exotic species introduced with oysters from North America was the predatory oyster drill, *Urosalpinx cinerea*, found in England in 1920. It is now well established on the southeastern and southern coasts. A gastropod competitor, *Crepidula fornicata*, which attaches to oysters in chains, exhibited fantastic populations in England on derelict beds called "mud and limpets" after its introduction about 1880 (Orton, 1937). It spread to the continent and is now distributed widely from Sweden to France. It has pelagic larvae but was probably spread mostly by man while attached to mussels and oysters. Other American species probably introduced with oysters, but exhibiting more subtle, noneconomic effects, include the bivalves *Petricola pholadiformis*, *Mya arenaria*, and a mud crab, *Rithropanopeus harrisi*, all now with wide distributions in northern Europe (ICES, 1972).

The introduction of *C. gigas* to France has added some oriental species to the fauna but their eventual status after importations ceased in 1975 remains to be determined (Gruet et al., 1976). The parasitic copepod *Mytilicola orientalis* may be the most destructive species introduced because it attacks both oysters and mussels. *Sargassum muticum*, an asiatic phaeophyte introduced with Pacific oysters, is established on the coasts of France and England (Maurin and LeDantec, 1979). It is spreading and interferes with the commercial species *Chondrus crispus*. Two other algal species have been introduced: *Undaria pinnafida* in the Mediterranean Sea and *Laminaria japonica* on the Atlantic coast of France. Five additional invertebrate species from the Orient have been collected in Brittany, including an annelid, a bivalve mollusk, an anthozoan, and two barnacle species (Gruet et al., 1976). The two oyster pathogens that appeared immediately after the first introductions of *C. gigas* are probably exotics from Japan also. The elimination of the Portuguese oyster from France and the serious reduction of production of the flat oyster are the most dramatic consequences of importation of *C. gigas*.

The importation of tropical *C. rhizophorae*, the mangrove oyster, from French Guyana to France defies explanation. Why this oyster should be expected to survive in the cold waters of the French Atlantic coast is not evident and its use in French oyster culture is obscure. Continued importations present the threat of introducing oyster diseases and parasites of the western Atlantic (Maurin and Gras, 1979).

Exotic Mollusks on the Pacific Coast of North America

A long list of exotic biota introduced from New England and Japan has been compiled by Hanna (1966) and Dundee (1969). The long periods of repeated oyster importations offered many opportunities for establishment of exotic species in this mild oceanic-type climate. Species capable of breeding at temperatures of 20°C or less, or finding warm niches, were successful colonizers. The introduced mollusks exemplify the opportunities provided immigrant species by man's importations. In the early years, no care was exercised in cleaning shipments of oysters from New England or Japan of unwanted aliens. Bonnot found 22 species of marine shells in 20 boxes of Japanese seed in 1930 (Hanna, 1966).

All three commercially important bivalves on the Atlantic coast of North America were imported early to the West Coast. *Mya arenaria*, apparently introduced accidentally with oyster transplantations, was immediately successful because of its adaptation for breeding at low temperatures. It is now distributed from Alaska to San Diego. The American oyster, *C. virginica*, and the hard clam, *Mercenaria mercenaria*, did not reproduce successfully which necessitated continued importations to produce crops. Both species can be grown commercially on the West Coast using hatchery seed.

Several western Atlantic mollusks closely associated with oysters for food or substrate achieved distributions on the West Coast in localized niches where oysters are grown. The oyster predator, *Urosalpinx cinerea*, is often found on oyster beds but not in all

areas where salinities are favorable. All three species of *Crepidula* (*C. fornicata*, *C. convexa*, and *C. plana*) were introduced but only *C. fornicata* became established with a preference for the warm diked waters used for *O. lurida* culture. Many imported exotics were first observed with oysters in local seafood markets (Hanna, 1966). *Modiolus* (*Guekensia*) *demissus* was very common on the warm intertidal shores of San Francisco Bay during the years of oyster imports and was sometimes marketed. The common eastern mud snail, *Nassarius* (*Ilyanassa*) *obsoletus*, is now localized in warm bays where *C. virginica* was imported. Several small mollusks such as *Gemma gemma* from the East Coast and *Batillaria zonalis* from Japan are widely established in Puget Sound and California. Some mollusks, e.g., *Arca transversa* and *Busycon canaliculatus*, were present only as long as imports continued because they did not breed.

The most spectacular accidental invasion of West Coast ecosystems was made by the Japanese clam *Venerupis japonica*. It has a wide distribution and great abundance in Japan. It has been highly successful on the West Coast and has filled a warm intertidal niche not occupied by native clams (Quayle, 1964). It is widely accepted both ecologically and as a convenient shellfish for human food. Several species of *Venerupis* endemic to western Europe are also used for food, and are cultured there in hatcheries for commercial plantings. The Japanese oyster drill, *Ocenebra japonica*, is common on West Coast oyster beds from accidental importations.

Two nonmolluscan species introduced to the West Coast from Japan are serious parasites of oysters and mussels. The flatworm predator *Pseudostylochus ostreophagus* kills oyster spat in Puget Sound and is difficult to control. A macroscopic red copepod, *Mytilicola orientalis*, infests intestinal tracts of mollusks which affects their glycogen condition and saleability (Glude, 1975). This copepod genus is more serious as a parasite of mussels than of oysters. An extensive literature exists on *M. intestinalis*, the western European species (Marteil, 1976). Parasites and diseases have the advantage of often being able to attack new hosts when introduced to a new ecosystem, and they survive transportation easily in mollusk hosts.

The Role of Importations in Spreading Diseases and Parasites

Along any given continental coast there are marine communities, isolated for thousands of years by physical barriers, that had no opportunity to exchange fauna with neighboring areas until modern man and his transportation arrived. Many races of *C. virginica* occur along the North Atlantic coast of America (Stauber, 1950) and they appear to have retained their genetic traits despite much transplanting between regions. By transplanting oysters across these natural barriers, man has provided many opportunities for parasites and diseases to find susceptible hosts.

Malpeque Bay Disease in Canada (1914)

The most infamous mortality of oysters in North America was caused by Malpeque Bay Disease in the eastern Canadian provinces (Needler and Logie, 1947). Oysters from New England were imported into Malpeque Bay, Prince Edward Island, in 1914. This was to supplement reproduction which had become inadequate from overfishing and depletion of stocks (Needler, 1931). A severe mortality first occurred in 1915-16 and the epizootic continued until about 1930. The native oysters achieved resistance in a few generations, but over a long period due to infrequent spatfalls (Logie, 1956). The disease spread slowly around the bays of the Island and in 1952-55 it spread to tributaries of mainland New Brunswick in the Gulf of St. Lawrence. The causative organism has not been demonstrated although exposure of susceptible oysters from Bras d'Or Lakes shows that the pathogen is still present. Curiously, the disease has not been associated with mortalities in the New England area from which it was supposed to have originated.

Delaware Bay Disease On Mid-Atlantic Coast of North America (1957)

The oyster industry of the Mid-Atlantic Coast was crippled by the sporozoan pathogen *Minchinia nelsoni* which appeared in Delaware Bay in 1957 (Haskin et al., 1966), and in Chesapeake Bay in 1959 (Andrews and Wood, 1967). More than 90 percent of oysters growing in the two bays in waters >15‰ salinity were killed within 2 years.

The origin of this disease is unknown but imported oysters is a likely explanation (Rosenfield and Kern, 1979). Many small lots of exotic oysters have been planted along the East Coast from Louisiana to Maine (Dean, 1979). Often mature oysters were brought in secretly so that no records of the origins or the histories of importations exist. A few examples will illustrate the pattern of these careless importations.

Recently, *C. gigas* from the West Coast of North America was planted in Maryland waters by a seafood dealer which resulted in a specific law in that State prohibiting the species. The oysters were recovered as completely as possible by scuba diving. An oysterman from Delaware saw impressive specimens of *C. gigas* at the Seattle World's Fair in 1962 and he had some sent to his home state for planting. The oysters were confiscated by a biologist who held them in trays in open waters in Rehoboth Bay, Del., for several years without serious mortality or apparent successful reproduction. *Crassostrea gigas* was apparently resistant to Delaware Bay disease which at that time killed *C. virginica* in Rehoboth Bay.

A bushel of *C. gigas* was planted in Barnegat Bay, N.J., in the early 1930's. These oysters failed to grow, which is unusual for this species, and they died over a 2-year period. A shipment of *C. cucullata* (= *C. commercialis*) failed to survive air travel from Australia to New Jersey in the care of T. C. Roughley (Nelson, 1946). Two eminent scientists were involved which reflects the attitude toward importations at that

time. None of these known incidents fits precisely the timing of arrival of the pathogen *M. nelsoni* in Delaware Bay.

For about 6 years prior to the appearance of Delaware Bay disease, seed oysters from the James River and Seaside of Eastern Shore, Virginia, had been transplanted to Delaware Bay in large quantities. It is now known that Seaside oysters are infected with an endemic pathogen, *Minchinia costalis*, which is closely related to *M. nelsoni* (Andrews, 1979a). Possibly by hybridization or mutation, a new virulent race of pathogens arose in Delaware Bay waters (Andrews, 1968). However, I believe it is more likely that the pathogen *M. nelsoni* was introduced from Asia.

Sacculinid Parasite of Mud Crabs Introduced From Gulf of Mexico (1962-63)

One last example can be documented of an oyster transplantation that greatly altered crab populations in Virginia. This event illustrates the complexity of such faunal changes. Disruption of oyster production in Virginia by Delaware Bay disease caused oystermen to search for new sources of supply. Live oysters were trucked from the Gulf of Mexico (Louisiana, Texas, and Florida) to Virginia for shucking at waterside plants where shells and wastes were discarded near native oyster beds.

A year or two after importations began (1962-63), two dominant species of mud crabs, *Eurypanopeus depressus* and *Rithropanopeus harrisi*, were found to be infested with a castrating sacculinid (cirripede) parasite (*Loxothylacus panopaei*) (Van Engel et al., 1966). These formerly dominant crab species, which were major scavengers of dead oysters, soon became scarce and have remained rare for 15 years to the present. A third crab species, *Neopanope texana sayi*, formerly rare on oyster beds in Chesapeake Bay, became abundant and is now the dominant mud crab. It is not susceptible to the parasite.

Fortunately, no new oyster diseases were introduced with these Gulf of Mexico transplantations. It is suspected that another disease caused by *Perkinsus marinus* (formerly *Dermocystidium marinum*) was introduced to Chesapeake Bay with seed oysters from South Carolina or the Gulf of Mexico prior to 1940 (Andrews and Hewatt, 1957).

Biological Planning for New Importations

The rationale for introducing new species of commercial organisms is usually economic and political, and not based on biological need. It could be argued that survival of the fittest is the most rational way to handle exotic oysters. Presumably, this could be justified by the success of *Crassostrea gigas*, the Pacific oyster, on the major oyster-growing coasts of the temperate zones of the world. It has succeeded biologically in western Europe, Tasmania, New Zealand, and the West Coast of North America as well as its native areas on eastern Asian coasts. It is vigorous, fast-growing, relatively disease resistant, and increasingly accepted as a raw-bar oyster due to rapidly changing economic and social mores (Bourne, 1979). Why not accept this superior oyster as the standard for temperate zone ostreid culture? *Crassostrea gigas* was also tried in tropical regions of the South Pacific with poor results (Bourne, 1979). Fortunately, most consultants and FAO officials are recommending use of native oysters in the tropics.

The French decision to introduce *C. gigas* has greatly altered oyster culture in Europe (Marteil, 1969, 1976). French oyster growers are adapting the technology of culture to *C. gigas* with new cultural methods and using new areas in Brittany where *C. angulata* was not grown. After excessive spatfalls occurred in the early 1970's, culminating in the hot summer of 1976, there have been spatfall failures. The effects of the parasitic copepod *Mytilicola orientalis* and introduced fouling organisms are yet to be determined. The rapid spread of gill disease resulted in elimination of *C. angulata*, the Portuguese oyster, from France, and Aber disease caused a severe decrease in *Ostrea edulis* production (Alderman, 1979).

Once introduced into southern France, it was probably inevitable that the Pacific oyster would spread rapidly in Europe. The economic and political decision to hasten the replacement of *C. angulata* by *C. gigas* involved additional risks, but sustained the French industry without serious reductions in total production (Maurin and LeDantec, 1979). The Atlantic coast of France was the major source of seed of *O. edulis* for Holland and some *C. angulata* for Great Britain. The cutoff of seed oysters encouraged development of hatcheries in Great Britain to produce *C. gigas* spat for England, Germany, and France. *Crassostrea gigas* is now established as wild stocks in Holland and also grown in the Adriatic Sea and the Mediterranean Sea (France).

The proponents of use of *C. gigas* in New England argue that land and cold water barriers would prevent larvae from spreading southward (Dean, 1979). But man is the problem. No laws or regulations will prevent the tourists in Maine from taking home to Chesapeake Bay waters live oysters sold for raw consumption. From Massachusetts southward the warm summers of our continental climate should permit *C. gigas* to reproduce successfully. The spatfalls could be excessive and cover all objects in the water as has occurred in the Arcachon area of France. *Crassostrea virginica* already exhibits this tendency in South Carolina, Georgia, and some areas of the Gulf of Mexico. It is not conducive to production of quality oysters (Hopkins, 1954).

The careful introduction of *C. gigas* into Maine through hatcheries and quarantine methods to avoid diseases and pests (Andrews, 1979) is most desirable in contrast to the French approach of mass importation. Yet elimination of many agents of biological control provides the exotic species with a contrived advantage in competition with the native oyster. Provided it does not encounter an endemic disease to which it is susceptible, the Pacific oyster should thrive on the Atlantic coast. This species is an intertidal oyster whose breeding populations escape many subtidal enemies. Miyagi oysters (northern race) also tend to reproduce and grow in slightly colder waters

than comparable native races (Hickey, 1979). The argument that *C. gigas* has had opportunities to establish itself through careless importations is not persuasive because circumstances and conditions of importation were not known.

Attitudes and Rationales for New Introductions

It is no longer tolerable to permit the whims of individual citizens and scientists to determine the distribution of exotic species in an increasingly cosmopolitan manner. Courtenay and Robins (1973) described the minimal research and public review activities that should precede intentional introductions even for the best of rationales, such as biological control of established pests. It should not be necessary for each state or country to prohibit each species individually by specific laws. All marine importations should be made under appropriate licensing authority after public review and with clear obligations of control of organisms and responsibility for negative consequences. In the case of commercial species such as oysters, exportations should be subject to the same controls as importations. They should not remain private decisions of individuals or agencies whose motives may be profit or ego satisfaction.

The rationale or reasons for introducing a new oyster species must offer more advantages than just bringing a new competing species to a coastline. Importations may benefit one sector of a coast and endanger a commercial industry in another sector. It is important to determine how widely the new species will spread naturally and with man's help. Except for special niches (e.g., Pendrell Sound), *C. gigas* does not reproduce regularly on the Pacific Coast of North America, yet it spread widely during occasional warm years and persists without recruitment as breeding populations for many years (Quayle, 1969).

Ostrea edulis is now grown in Maine by hatchery reproduction from a small wild population adapted to the Gulf of Maine over a 30-year period (Welch, 1966). The flat oyster is a temperature-sensitive species that does not survive in the warm summer waters of Chesapeake Bay. It does not pose a threat in terms of growth and competition with the cultured native oyster south of New England. However, careless importations could introduce diseases and pests. The European shell disease prefers warm waters (Alderman and Jones, 1971). If imported, it could have disastrous effects on native oysters along our coast. It is reported to occur in flat oysters on Prince Edward Island in open waters after hatchery rearing in quarantine[1].

It is assumed that future importations of shellfish species will be made under quarantine conditions using hatcheries to produce disease-free and parasite-free progeny for testing and eventual release in open waters. This technique has proven to be feasible with oysters, and it overcomes the most serious problems of introductions in the past. However, this method is slow and has not been practiced in distributing *C. gigas* to Europe in recent years, except in Great Britain (Walne and Helm, 1979).

The times and quantities of recent French importations are not readily available in the literature despite the large volume of papers on the new diseases. No description of *C. gigas* importations is given in a comprehensive review of French shellfish culture (Marteil, 1976). An uninformed reader may not realize that the Pacific oyster is an exotic species in France. Ranson (1967) showed that the prodissoconchs or larval shells of *C. gigas* and *C. angulata* are indistinguishable and Menzel (1974) claimed they are the same species. Even if the oysters are accepted as cospecific, isolation from each other for several centuries is certain to have altered their immunities to diseases. Pathogens similar to those causing mass mortalities in eastern North America and western Europe have been found in Asiatic and Australian oysters (Kern, 1976; Sindermann, 1976; Perkins and Wolf, 1976). Trial introductions of shellfish into several countries of Europe are documented by ICES (1972).

Competition With Native Species

The most important aspect of competition is the ability of exotic oyster species to reproduce successfully in new environments. On oceanic-type coasts in the temperate zone, *C. gigas* is limited in its reproduction by low summer temperatures. However, it is successful to the point of severe crowding in southwestern France. Temperatures for breeding are no problem for *Crassostrea* species on coasts with continental-type climates. However, the races of *C. gigas* evolved in Japan with salinities near oceanic level may not tolerate the low salinities found in Chesapeake Bay and other southern estuaries during winter and spring.

The amount of competition between exotic and native species depends upon usage and relative adaptations of exotics to the new environments. In a region, such as northern Europe or New England, that depends on hatchery-produced seed oysters, there is no reproductive competition. Therefore, the most serious problem is eliminated. In the Netherlands, *C. gigas* has reproduced naturally in two recent years and competition with *O. edulis* may occur for space and food. However, *Crassostrea* species tend to set and survive most intensively in intertidal zones which reduces the competition for space. *Crassostrea gigas* grows faster than its native competitors in Australia (Medcof and Wolf, 1973), western Europe (Marteil, 1976) and eastern North American (Hickey, 1979).

Excessive reproduction of oysters in an area results in slow growth and stunting. This is characteristic of seed oyster areas. Accumulation of successive year classes of young oysters on growing stocks is particularly harmful when shellfish are intended for raw-bar trade, as in Europe where appearance is important.

When crowding of oysters encompasses most growing areas of a region, such as in Seaside Virginia, South Carolina and Georgia coasts, and many

[1]Drinnan, R. E., Fisheries and Environment Canada, Halifax, N.S., Canada. Personal commun., 1979.

Gulf of Mexico estuaries, harvesting may require steaming and shaking out meats for canned products. These canned oysters involve much waste of small oysters and they bring the lowest price of all shellfish preparations (Lunz, 1954). Excessive reproduction in an estuary or region inhibits efficient culture and is almost impossible to alleviate.

The potential effect of excessive populations of exotic oysters on other species in an ecosystem can only be surmised. Predators, diseases, parasites, and fouling organisms are likely to increase when excessive abundance of an exotic occurs from an irreversible introduction. The full consequences can only become apparent with time. The most desirable introduction would be one where reproduction of the species is limited by temperatures or isolated by hydrography to a few favorable seed areas. This now occurs in Delaware Bay and Chesapeake Bay with the native oyster *C. virginica*. A good example of a successful introduction of a species with limited reproduction areas is *C. gigas* on the West Coast of North America.

Importance of Races

There are many races of *C. virginica* along the Atlantic Coast of North America. These were first recognized because southern oysters failed to breed in New England waters (Stauber, 1950). Morphological traits of shell thickness and shape persist when oysters from several regions are grown in trays in Chesapeake Bay. Differences in susceptibility and resistance to diseases are exhibited by races not previously selected by the pathogens (Andrews, 1968). Isozyme characterization has shown regional genetic differences along the Atlantic Coast[2] despite much transplanting.

Experience has taught oystermen to use local seed oysters if available. Some disastrous losses occurred in oysters transplanted from other regions. Thin-shelled oysters from Seaside of Eastern Shore, Va., suffered severe drill predation when introduced to Delaware Bay in the 1950's. South Carolina oysters showed severe winter kills and remained poor when transplanted to Seaside of Virginia. The Malpeque Bay disease in Canada followed transplantation of New England oysters. It is the classical example of the consequences of mixing oyster races along a coast.

In Virginia, at least three races of oysters are known by growth habits, shape, and susceptibility to diseases and predators. Most distinctive are fast-growing thin-shelled Seaside oysters. Spatfall is excessive and predation intensive. Therefore, rapid growth and early harvesting are necessary. One might attribute all these traits to the environment, but the oysters fail to grow and survive well in low salinity waters within Chesapeake Bay. In contrast, Potomac River oysters are acclimated to low salinities, but are notable for their susceptibility to diseases, particularly *Minchinia nelsoni* (Andrews, 1968). They, too, exhibit vigorous growth and achieve larger sizes than Seaside oysters. The typical oyster of Chesapeake Bay is exemplified by James River seed oysters which Nelson[3] believed were genetically selected for slow growth by 100 years of tonging the largest ones for market. Their small mature size may be a consequence of early stunting in the unfavorable growing conditions of James River. These three races illustrate the genetic adaptations necessary to grow oysters in only one region of the Atlantic coast.

In Europe, winter hardiness of *Ostrea edulis* is a problem when seed oysters are transplanted from regions with warmer climates. Since the severe winter kill of natives in 1962-63, the Netherlands is dependent on seed oysters from Brittany. A culture of one warm-season is followed because the French race is less hardy than natives (Korringa, 1976). There is also the threat of Gill and Aber diseases from importing French oysters.

In eastern Canada, *Ostrea edulis* introduced from Conway, Wales, in 1957-59 did not survive the cold winters. A stock from Holland (Loosanoff, 1955) was found to be hardy in Prince Edward Island (Medcof, 1961) after nearly three decades of selection in the cold waters of the Gulf of Maine.

Even vigorous *C. gigas* may encounter difficulties in adaptation along the Atlantic coast from low salinities, warm climates, and diseases and predators. Depending upon the races introduced from Asia, the species could be limited to certain areas and hydrographic regimes. Since numerous races of *C. gigas* probably occur along the Asian coast, it would be advantageous to fit each new region with a race from a comparable climate on the coast of origin (Newkirk and Haley, 1977). Much needs to be learned about races with respect to diseases, climates, and genetic parameters of oysters before this is done. To learn by trial and error from hasty, unplanned imports has unacceptable risks for the industry and for the stability of present ecosystems.

The Role of Hatcheries in Importations

Most importations of exotic oysters in the past have been from natural sets of adult oysters or spat on shells grown in open waters. This made inspections for diseases and pests difficult if not impossible. The development of commercial and experimental hatcheries in most major oyster-growing areas of the world has made it possible to avoid these problems. Hatchery-reared spat of 2-5 mm may now be obtained a few weeks after setting without exposure to natural waters. Thousands of tiny live spat are shipped safely by air to distant countries at small cost. The subsequent handling of tiny spat in commercial numbers to prevent predation and smothering is tedious and costly, however.

To avoid these problems of early handling of cultchless spat (Andrews and Mason, 1969), many hatcheries have returned to the technique of setting on shells or shell fragments which facilitates early planting on oyster beds. These lots must soon be planted in open

[2]Anderson, W. W. University of Georgia, Athens, Ga. Personal commun.

[3]Nelson, T. C. Rutgers University, New Brunswick, N.J. (Deceased). Personal commun.

waters and hence carry the same risks as wild oysters for importations. In the decade between 1966 and 1975, the French imported 500 tons of adult oysters and 7,100 tons of spat on shells. All of these were wild oysters from British Columbia, Canada, and Japan, respectively.

Preimportation Studies Needed and Controls Required

The rationale for introduction of *C. gigas* is based on its vigor and fast growth. It appears to grow faster and during the cold season longer than native *C. virginica*. This applies only to the Miyagi race which is the only one tried in most new areas.

Crassostrea gigas presents the potential difficulties of: 1) Competition and hybridization with *C. virginica*, 2) probable susceptibility to some native diseases, and 3) some question as to its marketability as raw oysters in competition with the native oyster. It also may be expected to spread all along the North Atlantic coast and compete directly with native *C. virginica* for food and space in nearly all salinity regimes and environments. One must be prepared for replacement of the native oyster.

In the opinion of the author, *C. gigas* could be a useful species in New England where artificial reproduction in hatcheries can compensate for failure of natural spatfalls. However, based on hatchery seed, *O. edulis* and selected strains of *C. virginica* offer equal or better opportunities for culture of raw-bar oysters. *Crassostrea gigas* presents high risks in southern waters where it may be expected to reproduce naturally and to compete strongly and possibly interbreed with native oysters. These advantages and disadvantages of *C. gigas* will be discussed and contrasted for two large sectors of the coast, south and north of Long Island, N.Y.

The oyster-producing areas in the states south of Long Island generally have adequate spatfalls of *C. virginica* rather regularly, or they have the potential to yield large seed oyster crops if properly managed. The resurgence of Delaware Bay seed beds in the 1970's after severe losses to *Minchinia nelsoni* in the 1960's is evidence of this capacity. Moreover, the oyster industries in the south are much more productive than those in the north despite much lower market prices and greater problems of diseases and predators.

North of Long Island, the major oyster crop is raw-bar oysters which sell for high prices thus compensating for relatively low production. Supply of seed oysters is a constant problem in the north except in occasional years of intensive sets. Furthermore, slow growth in cold waters prolongs the cycle of marketable crops.

These factors provide a division of interests in use of exotic oysters and production of seed oysters in hatcheries. In the north, the cost of hatchery seed is not prohibitive where natural spatfalls do not occur, and the fast-growing *C. gigas* has an added appeal. Drinnan[4] reported that *C. gigas* outgrew *C. virginica* at Ellerslie, Prince Edward Island, 4 to 1 by dry meat weights over a period of 12 months in open waters. A recent report on tray-grown spat of the two species in a Massachusetts cove closed to a pond in the warm season also found faster growth in *C. gigas* (Hickey, 1979). Another commercial operation using *C. virginica* hatchery spat in trays is being conducted by Cotuit Oyster Co.[5] because of scarcity of natural seed in Massachusetts (Matthiessen, 1979). Biologists in Maine would like to replace native *C. virginica* with hatchery-grown *C. gigas*, along with hatchery seed of *O. edulis* already being grown in floats (Dean, 1979). The failure of *C. gigas* to reproduce in Massachusetts and Maine waters is a strong argument for use of hatchery seed in these northern waters. The risk of these exotic species spreading is thereby minimized.

In the southern sector of the North Atlantic coast, faster growth of *C. gigas* may be completely nullified by losses resulting from native diseases, slower growth in warm summer temperatures, and due to low salinities in seed areas. The fouling of native or exotic oysters on growing and fattening beds by heavy spatfalls of *C. gigas* would be disastrous to the Mid-Atlantic coast industry. Hatchery production of seed oysters in the south is not economically feasible yet. Unless *C. virginica* is replaced by *C. gigas*, the problem of separation for marketing of two easily distinguished species growing side by side may occur. Both quality of meats (fatness and taste) and differences in appearance of meats and shells will probably be noticeable to consumers. The proximity of *C. gigas* in New England would enhance the chances of accidental introduction in the south. Self-appointed "experimenters" could easily buy shell stock in Maine and transplant it to Chesapeake Bay for later "eating." Enactment and enforcement of laws to protect against this type of transplanting are not feasible. Canadian importations of both *C. gigas* and *O. edulis* are not discussed further since additional barriers of distance, cold waters, and a national boundary provide added protection.

Introduction of *C. gigas* cannot strictly be said to have occurred in New England until natural wild populations occur, although some oysters are being held in Maine and Massachusetts. In the south, where it is not needed, much additional information should be collected before releasing this species in open waters. The necessary tests are going to be difficult to conduct, control, and interpret within quarantine systems. Needed topics of study include the following items.

1) Characterization of major native seed-source populations in eastern Asia and along the North American Atlantic coast before mixing and hybridization occur. This involves isozyme tests of large wild breeding populations in genetic equilibrium (Hardy-Weinburg law). This procedure is costly and tedious, and depends upon how many enzyme systems need to be tested and the number of oysters required to characterize races.

2) Testing of races of exotic and native oysters for critical temperatures

[4]Drinnan, R. E. Fisheries and Environment Canada, Halifax, N.S., Canada. Personal commun., 1973.

[5]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

and salinities that induce gonad maturation, spawning, and favorable growth of larvae. Tolerances to salinity regimes and reactions to temperature and salinity parameters in terms of survival and growth are needed for each species and its major races.

3) Long-term monitoring of exotic species in their native habitats for prevalences and effects of oyster diseases and parasites; and testing of exotic oysters for susceptibility to diseases native to proposed sites of importation. This involves coordination of research efforts in two widely separated regions or countries. Testing exotic species against native pests may prove difficult without exposure in open waters. Diseases may be unknown for certain regions and artificial infection techniques have not been developed for other pathogens and parasites.

4) Evaluation of comparative growth rates under various conditions of bottom types, intertidal exposure, depths, and phytoplankton regimes. The method of culture strongly influences growth rates and glycogen deposition. Oysters grow faster when suspended in the water, but currents, seasonal temperature regimes, duration of spawning season, and substrate type greatly influence growth and fattening.

5) Exploration of hybrids and selected strains for particular uses and adaptation to localities and needs. The availability of hatcheries provides great opportunities for hybridizing species and races and selection of superior strains to meet special conditions. Oysters resistant to sporozoan diseases have already been selected.

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Social Considerations Associated With Marine Recreational Fishing Under FCMA

CHAD P. DAWSON and BRUCE T. WILKINS

ABSTRACT—Research in the social and human behavior aspects of marine recreational fishing under the optimum yield objective of the Fisheries Conservation and Management Act of 1976 is reviewed and related to a generalized sequential model of recreation behavior. The outdoor recreational literature reviewed indicates that sociological researchers and managers involved in marine recreational fishing need to consider six general factors: 1) The motivations and expectations of fishermen; 2) the satisfactions and benefits of a fishing experience to fishermen; 3) typologies of various kinds of fishermen; 4) the preferences of fishermen for various fish species, management goals, and alternative regulations; 5) the social-demographic profiles of fishermen; and 6) the correlations and interrelationships between the variables which measure these study topics. Consideration of these social factors will help marine recreational fisheries managers develop regulations as specific as possible and yet provide for the highest quality fishing experiences for the most fishermen.

Introduction

Marine fisheries management has, in recent years, focused on the importance of social, economic, and biological factors in planning and management of our marine fisheries resources. Recognition of these three essential components has led to the concept of optimum yield (Roedel, 1975; Nielsen, 1976), which is the dominant management objective in P.L. 94-265, the Fisheries Conservation and Management Act (FCMA) of 1976. The FCMA defines optimum yield (OY) as the maximum sustainable yield, as specifically modified by relevant social, economic, and biological factors.

Under the FCMA guidelines, regional councils are required to develop management plans for each identifiable fishery unit; one objective is to apportion OY catches between domestic commercial and recreational fishermen and foreign fleets. Representatives of sport fishing groups and their constituents have expressed increasing concern over what they perceive to be inadequate attention to allocation for the recreational fishery (Clepper, 1978; Stroud, 1978). Decisions on allocation of catch to recreational fishermen are particularly difficult because of insufficient information concerning the impacts of management plans on the economics and sociology of recreational fishing, and the biological impacts of recreational harvests on marine fisheries resources.

The 1979 and 1980 National Statistical Surveys on marine recreational fishing being conducted under contract to the National Marine Fisheries Service will help provide some information such as participation, catch, effort, and on travel origins and destinations. However, comparatively little information is available that permits the incorporation of social considerations in planning for the management of marine recreational fishing; this concern has been expressed by several researchers in recent years (Bryan, 1976; Spaulding, 1976; Ditton, 1977; Speir, 1978; Lackey, 1979) and by a report prepared under contract to the National Marine Fisheries Service[1]. Another report recently prepared under contract to the National Marine Fisheries Service[2] describes

NOAA Photo.

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[1]Centaur Associates. 1979. Phase 1 report on social and economic information for management of marine recreational fishing: Identification of data needs and priorities for data collection. Report prepared for National Marine Fisheries Service, U.S. Dep. Commer., Wash., D.C., under subcontract with Human Sciences Research, Inc., 81 p.

[2]Edmonds, W. S. 1979. The development of methodologies to collect socioeconomic information regarding marine recreational fishing. Report prepared by Human Sciences Research, Inc. for National Marine Fisheries Service, Northwest Regional Office, Seattle, Wash., 132 p.

three prototype surveys which have been developed to collect some kinds of social, economic, and demographic data on marine recreational fishing.

This paper reviews some of the available literature on the social and behavioral aspects of marine recreational fishermen and fishing and suggests how this information can fit into a research framework to provide fishery managers with planning information.

Framework for Social Considerations

Research on the social and behavioral aspects of marine recreational fishermen can build upon earlier research on various outdoor recreation activities (e.g., hiking, freshwater fishing) (Bryan, 1976; Ditton, 1977). For example, wildlife managers have been concerned with the regulation and enhancement of wildlife resources for human benefits (Hendee and Schoenfeld, 1973). A review of outdoor recreation literature suggests that a conceptual model must be formulated so that social and behavioral research can proceed to identify and categorize the preferences, satisfactions, motivations, and other characteristics of marine recreational fishermen.

A behavioral model suggested by Driver (1976) defines recreation (e.g., saltwater fishing) as an experience, and recreation demand as a mix of preferences for an experience that is desired, expected, and in which satisfactions are sought (Fig. 1). Driver assumed that the behavior of each recreationist is not random but results from definite causes (e.g., past experiences, preferences, expectations) even though "1) the recreationist need not be consciously aware of these causes and preferences; 2) the behavior can be spontaneous, exploratory, or trial and error, as well as habitual or engrained in learning from similar past recreation experiences; and 3) the recreationist need not attempt to maximize his expected returns as would the classical economic man." The final social products from a recreational or saltwater fishing experience (Fig. 1) include both satisfactions (e.g., catch, relaxation, exercise) and benefits (e.g., improved health).

A similar conceptual model was proposed by Hendee (1974) as the "multiple-satisfactions approach" to resource management. His basic idea was that "... recreation resources offer people the opportunity for a range of experiences which, in turn, give rise to various human satisfactions. These multiple satisfactions may then lead to benefits—the ultimate goal of recreation-resource management. The nature of recreational experiences, and thus the satisfactions and benefits that follow, can be shaped by management of the surrounding physical, biological and social conditions."

When restating both of these conceptual models in terms of marine recreational fishing, it appears that the most direct products of recreational fisheries management are not only fish (a reasonable probability of catching one or more fish is a definite requirement) but also the fishing experiences which produce human satisfactions and benefits. While this statement is most applicable to recreational anglers it also applies to some extent to commercial fishermen who also value the social satisfactions and benefits which accrue to them during their fishing efforts (e.g., physical exercise, experiencing the ocean environment, pride in their occupation)[3].

Satisfactions are the specific and immediately gratifying pleasures from the various aspects of the fishing experience. Net satisfaction from a particular fishing activity is the sum of the satisfying experiences (e.g., relaxation, catch, companionship, enjoying nature, physical exercise) less the dissatisfying experiences (e.g., restrictive

[3]Peterson, S., and L. Smith. 1979. New England fishing, processing and distribution. Woods Hole Oceanographic Institution, Woods Hole, Mass. Tech. Rep. WHOI-79-52, 73 p.

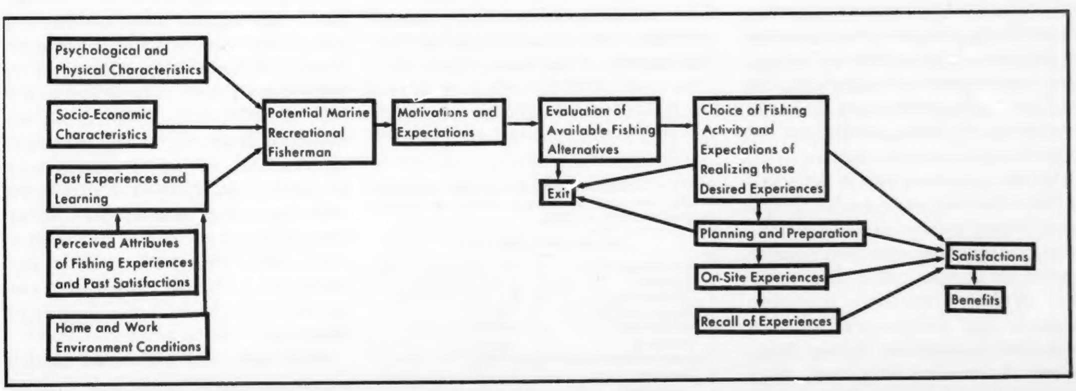

Figure 1.—A generalized sequential model of some social factors and decisions that determine the behavior of a marine recreational fisherman and the outcome of the experiences. (Adapted from Driver, 1976.)

regulations, user conflicts, poor weather, poor catch, equipment problems). Benefits are the general and more enduring conditions resulting from satisfactions. They may be evident in better physical health, improved psychological conditions (e.g., integrative achievements, mental well-being), and better social conditions (e.g., companionship) (Hendee, 1974).

The overall quality of a fishing experience is determined by the extent to which a fisherman experiences the mix of satisfactions which he or she desires. Since the components of desired benefits in a quality fishing experience differ for different individuals, a diversity of opportunities is needed. Thus, fishery managers need to consider such opportunities which provide for the highest quality experiences for the most fishermen (McFadden, 1969; Hendee, 1974; Hampton and Lackey, 1975; Driver, 1976).

Increasingly numerous studies have indicated that multiple factors motivate people to go fishing, although the relative importance of each factor has been open to considerable debate and misunderstanding (Ditton, 1977). For example, two rival hypotheses on the importance of catch to a fishing experience suggest that fishermen are either primarily interested in catching fish or they go fishing to seek satisfactions not directly related to catch. The simple testing of such rival hypotheses against each other will accomplish very little toward the understanding of the complex behavioral phenomena of recreational fishing, since they are dependent on the individual's avidity and experience, socioeconomic background, fish species sought, preferences for a particular type of fishing, fishing site and methods used, and other factors.

To date, most research in the social or behavioral aspects of marine recreational fishing has been conducted without regard for a comprehensive research framework (Ditton, 1977). The available outdoor recreation literature suggests that sociological research in marine recreational fishing needs to consider at least six general study topics: 1) The motivations and expectations of fishermen; 2) the satisfactions and benefits of a fishing experience to fishermen; 3) typologies of fishermen; 4) the preferences of fishermen for various fish species, management goals, and alternative regulations; 5) the social-demographic characteristics of fishermen; and 6) the correlations and interrelationships between the variables which measure these study topics (Hendee, 1974; Bryan, 1976; Driver, 1976; Ditton, 1977).

Review of Social Research

Motivations and expectations for marine recreational fishing experiences are the general and trip-specific incentives which activate an individual to participate in some form of marine recreational fishing (Fig. 1). The experiences of that activity lead to satisfactions and eventually benefits. Since motivations lead directly to satisfactions, and past satisfactions often form the basis for present or future motivations, researchers have tended to define and aggregate motivations and satisfactions into similar categories. Hendee and Bryan (1978) have identified 16 general categories that encompass virtually all of the motivations and satisfactions reported in 56 studies of outdoor recreation activities, especially studies of hunting and fishing (Table 1).

Motivational research to date has generally described the motives of freshwater fishermen but only a few studies have been directed toward marine anglers. Research on freshwater fishermen can offer some general guidelines toward investigating the motivations of saltwater fishermen.

Table 1.—General categories of motivations and satisfactions from outdoor recreation activities as reported by Hendee and Bryan (1978).

Motivations and satisfactions	
1. Nature appreciation	9. Environmental education
2. Escapism	10. Spiritual rejuvenation
3. Companionship	11. Experience a simpler life style
4. Social interaction	
5. Activity skills	12. Experience heritage
6. Display of accomplishments	13. Challenge
	14. Exercise
7. Enjoyment of equipment	15. Relaxation and general enjoyment
8. Consumptive use of natural resources	16. Vicarious experience and enjoyment

However, specific findings probably should not be generalized between freshwater and saltwater angling since these recreational experiences take place in different environmental settings. The experiences of a trout fisherman on a western mountain stream are inherently different from those of a bluefish angler on a charter boat off the Atlantic coast or a saltwater flyrod angler fishing tidal waters. The total mix of motivations and expectations (Table 1) for each of these activities will be different for each fisherman.

Sociological studies of freshwater fishermen indicate that motives for fishing are multiple, and that experiencing the natural environment, relaxation, and companionship were often rated by anglers as more important components of a fishing trip than were factors of catch (Moeller and Engelken, 1972; Knopf et al., 1973; Hampton and Lackey, 1975; Cox, 1977). However, Weithman and Anderson (1978) pointed out that the species, number, and size of the catch may "... make the difference between good or excellent fishing and an extremely enjoyable fishing trip, as opposed to fair or poor fishing and a moderately enjoyable fishing trip."

Research by Bryan (1974) and Spaulding (1970) indicated that marine recreational fishermen place high levels of importance on relaxation, experiencing the outdoor environment, and catching fish. Recreational fishermen entering a fishing contest in Victoria, B.C., and anglers using charter and party boats in New York reportedly placed a higher level of importance on catch than on other factors (Sewell and Rostron, 1970; Carls, 1976). However, a study of Texas charter boat fishermen reported that having fun, adventure, escapism, and companionship were more important motives for charter boat fishing than catching fish (Ditton et al., 1978). Fraser et al. (1977) suggested that charter boat fishermen are less catch oriented than party-boat fishermen.

While more studies of marine anglers are needed, the few preliminary studies available point out that motivations for marine recreational fishing are multiple

and that the relative importance of each motive varies with different types of fishermen. Catching some fish is an important motivation for marine recreational fishing but, as Ditton et al. (1978) suggest, catching fish does not necessarily mean a large number of fish since qualitative aspects of catch may be considered more important than quantitative aspects of catch.

Knowledge of the various expectations and motives for each type of fishing can provide some guidelines for fishery managers. For example, marine anglers may not be adversely affected by bag limit regulations, which, when used under appropriate conditions, can distribute the catch among more fishermen, as long as they still have a relatively high probability of catching one or more fish. Information on the expectations and motives of anglers can also help managers determine management alternatives which will help: 1) Meet expectations (e.g., by managing a fishery to produce a certain number or size of fish), 2) redirect expectations (e.g., through the dissemination of information on different and/or "underutilized" species that could provide an experience similar to the species originally sought), or 3) change expectations (e.g., through information and education programs on the need for catch allocations under OY).

Future research studies will need to develop direct and conclusive studies on motivations and expectations. These should better identify the various motives and their relative importance, and also begin to answer some of the questions about the formation of motives and the process of motivation change that leads a fisherman to seek different species, settings, equipment, and experiences.

Current measures of satisfaction for marine recreational fishing and the conceptual theories about satisfaction have not been completely developed yet or are only exploratory in nature (Ditton, 1977; Centaur Associates, Footnote 1). Further research is needed to develop adequate survey instruments which will obtain this type of social information. Additionally, some confusion has resulted from the use of motivations and satisfactions as synonymous terms. Past satisfactions contribute the motivation for immediate or future decisions to engage in an activity and both have been discussed in similar terms (Table 1), although they are the same in kind they are not the same in time (Fig. 1) and must be measured accordingly. Additionally, it should be noted that net or total satisfaction from a fishing experience includes both 1) the sum of the satisfying experiences less the dissatisfying experiences and 2) the disparity or congruence between the motives for fishing and the angler's perceived satisfactions. This type of research, which has been conducted with some wilderness users (Peterson, 1974; Snowden[4]) and river floaters (Graefe[5]), could be applied to marine recreational fishing to help identify possible ways of managing the fishing experiences to increase total satisfaction, and also to minimize the negative impacts that potential management plans or regulations would have on satisfactions and benefits. Benefits may be thought of here in terms of improved physical, psychological, or personal conditions for the fishermen. Hendee and Bryan (1978) noted that studies about benefits and the relationship of satisfactions to benefits are rare and that further research needs to be conducted.

Research identifying and separating various user groups or subgroups within hunters (Potter et al., 1973) and wilderness users (Hendee et al., 1968; Stankey, 1973) has been carried out, but similar work identifying different types of marine recreational fishermen has not been reported in the literature. The studies on hunters and hikers identified homogeneous subgroups or types who share some combination of similar motives, preferences, satisfactions or other factors important to their recreational experience. Similar research has been conducted by Kellert[6] on American attitudes, knowledge, and behavior toward wildlife and natural habitats. Ditton (1977) stated that management plans which consider the social needs and attitudes of the various subgroups of marine recreational fishermen will create greater satisfaction than plans that consider only the "average" fishermen.

Bryan (1976, 1979) concluded that there are four basic types of freshwater fishermen: 1) The "occasional" fisherman with novice ability and only casual interest in the sport; 2) the "generalist" fisherman who is interested in catching some fish in any environment by any legal method; 3) the "tackle-species specialist" who specializes in the skill of a particular angling method and/or angling for a particular species; and 4) the "method-species-setting specialist" who specializes in the method, species, and setting which make up a particular experience. These fishermen types are based on their degree of specialization in fishing and their specific motives and expectations involved in using the resource. Hendee and Bryan (1978) further postulated that fishermen advance into more specialized stages as they accumulate more experience. As a result they will seek different satisfactions from the same fishing activities over a period of development. Additionally, a fisherman may change from one user subgroup to another when he changes fishing activities because he may have different motivations for engaging in each variety of recreational fishing activity (Driver and Knopf, 1976). For example, an individual fishing for billfish on one trip and flounder on the next trip, will have different reasons for both angling experiences.

Manfredo et al. (1978) developed a typology of freshwater fishermen based on the different reactions of anglers to

[4]Snowden, M. R. 1976. Winter recreation in the Adirondack high peaks wilderness: User characteristics, attitudes and perceptions. M.S. Thesis, Dep. Natural Resources, Cornell University, Ithaca, N.Y., 103 p.

[5]Graefe, A. R. 1977. Elements of motivation and satisfaction in the float trip experience in Big Bend National Park. Masters Thesis, Dep. Recreation Parks, Texas A&M Univ., College Station, 170 p.

[6]Kellert, S. R. 1979. Public attitudes toward critical wildlife and natural habitat issues. Phase I report prepared for U.S. Dep. Inter. Fish. and Wildlife Service, Washington, D.C., 138 p.

fishing in a wilderness area. Their study was based on a multivariable cluster analysis of the various social attributes of the anglers and factors related directly to the fishing experience. Marine fishery managers could use this type of analysis to compare the degree of specialization, preferences, satisfactions, attitudes, or demographic characteristics (e.g., level of income, social groups, age) of various subgroups of marine fishermen and try to manage for the maximum positive mix of experiences desired by each group identified.

The preferences of recreational fishermen for various fish species, angling strategies, and management goals, strategies, or regulations need to be studied so that management plans actually respond to the wishes and preferences of the fishermen and not the values of the fishery managers (Stankey, 1977). For example, Hampton and Lackey (1975) reported a basic discrepancy between anglers' desires and managers' objectives or goals in some freshwater fishery management situations. Although these types of studies have been proposed for marine recreational fishing research, they have apparently not yet been carried out (Hester and Sorensen, 1978; Dawson[7]).

Social, economic, and demographic profiles of marine recreational fishermen need to be formulated, in addition to the collection of participation data relating to catch and effort. Such descriptive studies have been carried out in different areas and among various subgroups of marine fishermen (e.g., Sewell and Rostron, 1970; Cox, 1977; Ditton et al., 1978). Comparison of these data among various user groups, between different geographic areas and repeated periodically, will help to define the various fishermen constituencies and their characteristics.

Finally, studies are needed to examine the correlations and interrelationships between the five study topics discussed above: Motivations and expectations of marine anglers; their satisfactions and benefits from fishing; the various types of fishermen; their preferences for various fish species, management goals, and alternative regulations; and the social-demographic characteristics of marine anglers. This type of research may find that older fishermen primarily seek companionship whereas younger fishermen seek achievement. Multivariate analysis could help identify these relationships, as well as some measure of resource specificity for various subgroups of fishermen, resolution of current and potential fishing conflicts, acceptable substitutes for preferred fishing activities or fish species, and management regulations that would be most acceptable to each marine recreational fishing subgroup. Such information could be used to test management strategies, such as one suggested by Bryan (1976) in which the overall user welfare could be optimized by resolving conflicts in favor of those fishermen with more specific resource and motivational needs, since fishermen with more general resource and motivational needs would presumably have more alternate fishing opportunities.

[7]Dawson, C. P. 1979. Background information and management strategies for the development of recreational fisheries management plans in the Northeast Atlantic Fisheries Conservation Zone. M.P.S. Project Report, Dep. Natural Resources, Cornell University, Ithaca, N.Y., 70 p.

Conclusion

This review of social considerations in marine recreational fishing is not meant to be an exhaustive research document but rather an introduction and discussion so that both researchers and managers can begin to identify the needs for and begin the development of a conceptual framework that will improve optimum management plans for marine recreational fisheries. Additionally, we have tried to point out why certain research topics are important to both researchers and managers. For example, conflicts which have developed between various groups of fishermen can be partially understood through consideration of their motivations, expectations, and satisfactions. Tournament and fishing contest participants may be in conflict with other marine recreational fishermen since their interest in catch may promote a sense of competition which runs against the motivations of other fishermen—relaxation, companionship, experiencing the environment, and a change from the everyday work world. Conflicts such as these may be minimized by regulations on the promotion of contests and by having contests reaffirm the contemplative aspects of recreational fishing (Stroud, 1975).

Summary

The measurement of social considerations in OY management under the FCMA will require social and behavioral research that considers at least six basic topics in marine recreational fishing: 1) Motivations or expectations of fishermen, 2) satisfactions and benefits from fishing, 3) typologies of fishermen, 4) preferences for fish species, management goals, and alternative management regulations, 5) social and demographic characteristics of fishermen, and 6) correlations and interrelationships between the variables of these topics. Consideration of these social factors will help marine recreational fishery managers develop regulations as specific as possible and also provide a diversity of opportunities which offers the highest quality marine angling experiences for the most fishermen.

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Trends in Ex-vessel Value and Size Composition of Annual Landings of Brown, Pink, and White Shrimp From the Gulf and South Atlantic Coasts of the United States

CHARLES W. CAILLOUET and DENNIS B. KOI

Introduction

Caillouet and Patella (1978) and Caillouet et al. (1979, 1980) compared the commercial shrimp fisheries of the states bordering the Gulf of Mexico, using size composition of reported annual catches of brown shrimp, *Penaeus aztecus*, pink shrimp, *P. duorarum*, and white shrimp, *P. setiferus*, and its relationship to ex-vessel value of these catches. They compared these fisheries primarily because 1) the fisheries were regulated by different laws (Christmas and Etzold, 1977) resulting in different size compositions of shrimp harvested within the Gulf states, and 2) the ex-vessel value of the catches was influenced by the size composition of the catches. They showed that the average annual ex-vessel value per pound (expressed in dollar units based on the year 1975) for reported annual catches of shrimp in Texas was greater than that for other Gulf states from 1959 to 1975. They attributed differences in average annual ex-vessel value per pound to differences in size composition of the shrimp catches among the states. Because large shrimp commanded higher prices than did small shrimp on the market, and because a greater proportion of the reported catch from Texas was made up of large shrimp, the ex-vessel value of a given weight of catch was higher in Texas than in other Gulf states.

Size composition of a stock has long been used as a simple criterion for assessing status of a fishery (Henderson, 1972; Ricker, 1975). A decrease in average size of individuals can indicate an increase in mortality (usually equated with an increase in fishing mortality) or a decrease in growth (usually attributed to overcrowding). Socioeconomic factors also influence the size composition of the catches and landings in a fishery. Such factors affect strategies of fishing, culling of the catch, and marketing of the landings by fishermen. In most cases, socioeconomic forces override biological considerations in determining what the optimum harvesting strategies should be.

Caillouet et al. (1980) developed a simple exponential model to describe and characterize the size composition (expressed as cumulative percentage of weight by size category) of reported annual catches of shrimp. Using a logarithmic transformation, they simplified the model by converting it to a straight line equation, the slope of which was used to investigate fluctuations and trends in size composition of brown and white shrimp catches in Texas and Louisiana from 1959 to 1976. They detected trends toward decreasing size of brown and white shrimp in the reported annual catches in the two Gulf states.

Our paper uses exponential models to characterize 1) ex-vessel value per shrimp by size category, 2) size composition, and 3) ex-vessel value composition of the reported annual landings of brown, pink, and white shrimp from the Gulf and south Atlantic coasts of the United States from 1961 to 1977. Exponents of these models are used to investigate fluctuations and trends. Finally, simulations are conducted to predict the results of further changes in ex-vessel value by size category and in size composition of the landings.

ABSTRACT—Exponential models were used to characterize 1) ex-vessel value per shrimp by size category in reported annual landings, 2) size composition of reported annual landings (expressed as cumulative weight of landings by size category), and 3) ex-vessel value composition of reported annual landings (expressed as cumulative value of the landings by size category) for brown shrimp, Penaeus aztecus, *pink shrimp,* P. duorarum, *and white shrimp,* P. setiferus, *from the Gulf and south Atlantic coasts of the United States for 1961-77. Exponents of the models were used to describe fluctuations and trends in ex-vessel value per shrimp, in size composition, and in ex-vessel value composition of the annual landings of the three species on the two coasts.*

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Description of Data

The coastal shrimp fisheries of the Gulf have been described by Christmas and Etzold (1977), and those of the south Atlantic have been described by Calder et al. (1974).

Annual weight and value of landings for 1961-69 were obtained from the U.S. Fish and Wildlife Service (1962-71), those for 1970-76 were obtained from the National Marine Fisheries Service (1971-78), and unpublished data on annual weight and value of landings for 1977 were obtained from Richard L. Schween.[1] The weight of reported annual landings was expressed in pounds (heads-off, referring to shrimp with heads removed), and the ex-vessel value in dollars, by year (1961-77), coastal area (Gulf and south Atlantic coasts), species (brown, pink, and white shrimp), and size category, commonly referred to as "count" (number

[1]Richard L. Schween, Supervisory Computer Specialist, Resource Statistics Division, National Marine Fisheries Service, NOAA, Washington, D.C., pers. commun. January 1979.

of shrimp per pound, heads-off, including <15, 15-20, 21-25, 26-30, 31-40, 41-50, 51-67, ≥68, and "pieces"). English rather than metric units were used throughout our paper because they have been used historically, and information would be lost in their conversion. Count, as an expression of shrimp size, is equivalent to a reciprocal transformation of the weight (W, in pounds, heads-off) per shrimp as follows: count $= 1/W$. Landings used herein represented catches landed by domestic commercial fishermen at ports in each coastal area, for shrimping trips completed within each year along the respective coast, and reported by the National Marine Fisheries Service or its predecessor, the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service.

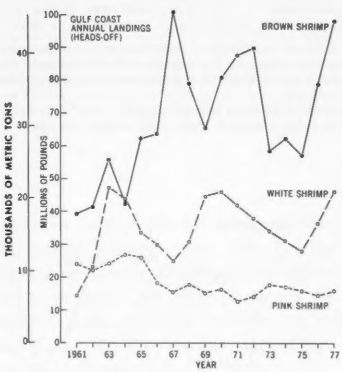

Figure 1.—Reported annual landings of brown, pink, and white shrimp from the Gulf coast, 1961-77 (based on U.S. Fish and Wildlife Service (1962-71), National Marine Fisheries Service (1971-78), and unpublished data).

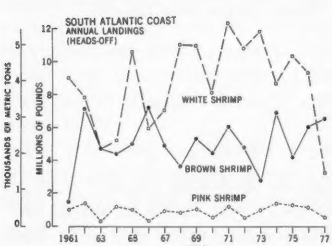

Figure 2.—Reported annual landings of brown, pink, and white shrimp from the south Atlantic coast, 1961-77 (based on U.S. Fish and Wildlife Service (1962-71), National Marine Fisheries Service (1971-78), and unpublished data).

Analyses and Results

Landings

Landings were dominated by brown and white shrimp (Fig. 1, 2). Brown shrimp landings usually exceeded those of white shrimp on the Gulf coast, and white shrimp landings usually exceeded those of brown shrimp on the south Atlantic coast. Pink shrimp landings were the lowest on both coasts. In 1977, the weight of the combined landings of brown, pink, and white shrimp was 15 times greater on the Gulf coast than on the south Atlantic coast. This characteristically large difference in weight of landings on the two coasts is one of the major differences between these two fisheries.

The analyses described herein were conducted for each species and both coastal areas separately to allow comparisons among species and coastal areas.

Annual Average Ex-vessel Value per Shrimp by Size Category

To characterize the relationship between annual average ex-vessel value per shrimp and size category with a simple linear function, we first divided dollars by pounds in each of seven (15-20, 21-25, 26-30, 31-40, 41-50, 51-67, and ≥68) of the nine size categories for each year. Next, we divided annual average ex-vessel value per pound in each of the seven size categories by the lower limit, C, of the respective size categories (15, 21, 26, 31, 41, 51, and 68) to obtain annual average ex-vessel value per shrimp, V, in each of the seven size categories for each year. Since lower limits of size categories were used as divisors, the calculated value per shrimp was the highest that could be obtained from the data for each size category. The following exponential model described the relationship between V_i and C_i for each year:

$$\widehat{V_i} = ae^{bC_i}$$

where V_i = annual average ex-vessel value per shrimp for the ith size category,
C_i = lower limit of the ith size category ($C_1 = 15$, $C_2 = 21, \ldots, C_7 = 68$),
$i = 1, 2, \ldots, 7$, and
e = base of natural logarithms.

A logarithmic transformation of the exponential model provided a simple linear function used to estimate parameters a and b of the model (Tables 1-3) by least squares.

Lower limits rather than midpoints of the seven size categories were used in the model because the size categories had unequal intervals. Upper limits of the size categories were not used because an upper limit could not be determined for the "≥68" category. A lower limit could not be determined for the "<15" category (zero was not realistic); also this category represented only a small fraction (≤5.2 percent) of the annual landings of any of the three species on the Gulf coast, and it was devoid of landings for all three species in most years on the south Atlantic coast. Therefore, the model did not encompass the value per shrimp in the <15 size category. The category "pieces" was disregarded, because it was assumed to represent all size categories in proportion to their representation in the landings. The magnitude of the constant, a, was influenced by our use of lower limits (rather than midpoints or upper limits) of size categories in fitting the model. The slope, b, of the logarithmic form of the exponential model was of greater interest as a simple index characterizing the relationship between value per shrimp and shrimp size. No lines were fitted for pink shrimp from the south Atlantic coast for 1965-72, because more than one of the seven size categories were devoid of landings in those years.

Table 1.—Relationship between transformed ex-vessel value per shrimp, ln$V$, and size category, C, for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

Year	Gulf coast a[1]	Gulf coast b[1]	Gulf coast Coefficient of determination r^2	South Atlantic coast a	South Atlantic coast b	South Atlantic coast Coefficient of determination r^2
1961	0.08010	−0.04491	0.977	0.08362	−0.04817	0.980
1962	0.11052	−0.04543	0.983	0.10168	−0.04556	0.981
1963	0.09904	−0.05298	0.988	0.07862	−0.04694	0.983
1964	0.09333	−0.04912	0.981	0.08404	−0.04678	0.985
1965	0.09643	−0.04762	0.982	0.08980	−0.04505	0.968
1966	0.12840	−0.04760	0.995	0.10584	−0.04168	0.972
1967	0.11541	−0.05137	0.978	0.08113	−0.04053	0.925
1968	0.16649	−0.05571	0.987	0.13461	−0.04844	0.978
1969	0.16835	−0.05295	0.994	0.13657	−0.04517	0.973
1970	0.15058	−0.05362	0.986	0.12891	−0.04681	0.969
1971	0.23915	−0.05851	0.992	0.19464	−0.05200	0.983
1972	0.23580	−0.05396	0.989	0.21576	−0.05199	0.984
1973	0.29406	−0.04895	0.995	0.27135	−0.04712	0.983
1974	0.27701	−0.05854	0.973	0.24749	−0.05649	0.949
1975	0.42151	−0.05666	0.998	0.31128	−0.04780	0.981
1976	0.53778	−0.05815	0.993	0.42919	−0.05298	0.972
1977	0.45506	−0.05636	0.986	0.39352	−0.05186	0.979

[1]Based upon least squares fit of ln$V$ on C, where V = annual average ex-vessel value (dollars) per shrimp in each of seven size categories, C = lower limit of each of the seven size categories, ln(a) = intercept, and b = slope; all slopes, b, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.

Table 2.—Relationship between transformed ex-vessel value per shrimp, ln$V$, and size category, C, for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

Year	Gulf coast a[1]	Gulf coast b[1]	Gulf coast Coefficient of determination r^2	South Atlantic coast a	South Atlantic coast b	South Atlantic coast Coefficient of determination r^2
1961	0.08431	−0.04755	0.987	0.08437	−0.04802	0.983
1962	0.10268	−0.04383	0.993	0.10230	−0.04807	0.981
1963	0.11110	−0.05101	0.990	0.07692	−0.04607	0.985
1964	0.09868	−0.05026	0.996	0.07613	−0.04310	0.973
1965	0.09773	−0.04679	0.991	—[3]	—[3]	—[3]
1966	0.10721	−0.04416	0.985	—	—	—
1967	0.12162	−0.04700	0.987	—	—	—
1968	0.14171	−0.05105	0.983	—	—	—
1969	0.16013	−0.05054	0.987	—	—	—
1970	0.16135	−0.05186	0.992	—	—	—
1971	0.21356	−0.05776	0.997	—	—	—
1972	0.26013	−0.05619	0.992	—	—	—
1973	0.24597	−0.04810	0.993	0.20882	−0.04207	0.961
1974	0.26840	−0.05392	0.960	0.31936	−0.05532	0.923
1975	0.30870	−0.05135	0.996	0.30546	−0.04761	0.944
1976	0.50282	−0.05566	0.995	0.52915	−0.05480	0.985
1977	0.43713	−0.05325	0.979	0.42047	−0.05282	0.963

[1]Based upon least squares fit of ln$V$ on C, where V = annual average ex-vessel value (dollars) per shrimp in each of seven size categories, C = lower limit of each of the seven size categories, ln(a) = intercept, and b = slope; all slopes, b, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.
[3]Data were lacking in more than one size category for 1965-72, so no lines were fitted.

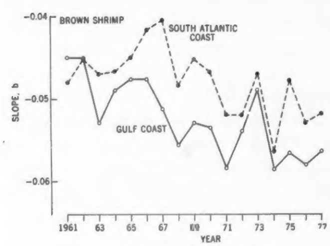

Figure 3.—Variations in slope, b, of the least squares fit of transformed ex-vessel value per shrimp, ln$V$, on size category, C, for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 1).

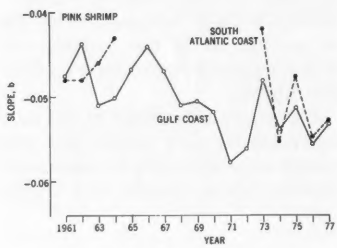

Figure 4.—Variations in slope, b, of the least squares fit of transformed ex-vessel value per shrimp, ln$V$, on size category, C, for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 2).

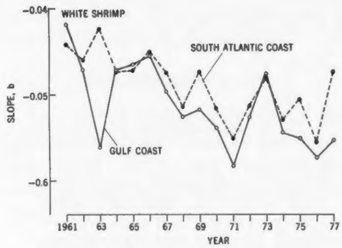

Figure 5.—Variations in slope, b, of the least squares fit of transformed ex-vessel value per shrimp, ln$V$, on size category, C, for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 3).

There were significant[2] downward trends in the slopes, b, of the relationships between ln$V$ and C for brown, pink, and white shrimp on the Gulf coast and for brown and white shrimp on the south Atlantic coast (Table 4; Fig. 3-5). These trends indicated that the differences in value per shrimp among shrimp in different size categories increased with time; in these cases, the value per shrimp increased more rapidly for larger shrimp than for smaller shrimp during 1961-77. No trend in b could be determined for pink shrimp on the south Atlantic coast, because of missing data for 1965-72 (Fig. 4), but annual levels of b for all species on both coasts paralleled each other to a great extent (Fig. 3-5). Such parallels would be expected if the economic forces affecting the relationship between value per shrimp and shrimp size in the landings in a given year had similar impacts on all three species on both coasts. The annual levels of b were higher (lower absolute

[2]Refers throughout this paper to the 95 percent level of confidence, unless otherwise noted.

Table 3.—Relationship between transformed ex-vessel value per shrimp, ln*V*, and size category, *C*, for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

	Gulf coast			South Atlantic coast		
Year	a^1	b^1	Coefficient of determination r^2	a	b	Coefficient of determination r^2
1961	0.08076	−0.04188	0.980	0.08741	−0.04421	0.973
1962	0.11439	−0.04709	0.984	0.11206	−0.04604	0.981
1963	0.10147	−0.05625	0.979	0.07303	−0.04237	0.976
1964	0.08797	−0.04716	0.970	0.09903	−0.04730	0.983
1965	0.09337	−0.04650	0.979	0.09852	−0.04724	0.988
1966	0.11814	−0.04557	0.984	0.11282	−0.04497	0.996
1967	0.12345	−0.04975	0.976	0.11387	−0.04755	0.977
1968	0.16171	−0.05269	0.979	0.15609	−0.05148	0.989
1969	0.16180	−0.05182	0.990	0.15174	−0.04745	0.991
1970	0.15420	−0.05401	0.987	0.14960	−0.05169	0.985
1971	0.24147	−0.05834	0.989	0.23077	−0.05525	0.987
1972	0.24393	−0.05277	0.986	0.22812	−0.05136	0.977
1973	0.29471	−0.04763	0.993	0.29985	−0.04812	0.995
1974	0.26805	−0.05459	0.972	0.24536	−0.05297	0.978
1975	0.40884	−0.05523	0.997	0.37067	−0.05063	0.992
1976	0.53710	−0.05737	0.990	0.50905	−0.05560	0.987
1977	0.43628	−0.05540	0.983	0.33953	−0.04748	0.983

[1]Based upon least squares fit of ln*V* on *C*, where *V* = annual average ex-vessel value (dollars) per shrimp in each of seven size categories, *C* = lower limit of each of the seven size categories, ln(*a*) = intercept, and *b* = slope; all slopes, *b*, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.

Table 4.—Trends in slopes, *b*, of the least squares fit of transformed ex-vessel value per shrimp, ln*V*, on size category, *C*, for reported annual landings of brown, pink, and white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Tables 1-3)[1].

	Brown shrimp	Pink shrimp	White shrimp
Gulf coast trend[2]			
Intercept	−0.0041	−0.0147	−0.0082
Slope	−0.0007*	−0.0005*	−0.0006*
Coefficient of determination	0.606	0.427	0.444
South Atlantic coast trend[2]			
Intercept	−0.0149	—[3]	−0.0135
Slope	−0.0005*	—	−0.0005*
Coefficient of determination	0.352	—	0.476

[1]Asterisk indicates that the slope of the trend (i.e., the change in slope, *b*, per year) was significantly different from zero at the 95 percent level of confidence.
[2]Represents the least squares fit of *b* on *x*, where *x* is the last two digits of each year, 1961-77.
[3]No trend was determined because data were lacking for 1965-72 (see Table 2).

Table 5.—Relationship between transformed cumulative weight of landings, ln*P*, and size category, *C*, for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

	Gulf coast			South Atlantic coast		
Year	c^1	d^1	Coefficient of determination r^2	c	d	Coefficient of determination r^2
1961	72,282,311	−0.04128	0.982	10,477,598	−0.08261	0.992
1962	59,236,591	−0.02753	0.992	40,287,830	−0.07094	0.980
1963	93,356,868	−0.03484	0.984	49,421,692	−0.09644	0.975
1964	72,145,105	−0.03649	0.998	58,712,312	−0.11128	0.990
1965	101,422,955	−0.03130	0.997	84,442,383	−0.10712	0.932
1966	94,011,719	−0.02844	0.982	81,749,479	−0.09798	0.962
1967	166,870,730	−0.03190	0.982	792,870,133	−0.18494	0.856
1968	123,211,137	−0.02775	0.991	42,934,661	−0.10861	0.992
1969	91,699,731	−0.02343	0.997	74,904,161	−0.10873	0.971
1970	120,245,976	−0.02832	0.992	42,153,151	−0.09897	0.994
1971	132,019,474	−0.02663	0.986	42,744,026	−0.08134	0.976
1972	146,015,012	−0.03073	0.991	34,649,366	−0.07966	0.968
1973	80,892,365	−0.02313	0.996	20,989,860	−0.07895	0.948
1974	88,903,316	−0.02643	0.977	38,875,703	−0.06507	0.932
1975	85,276,545	−0.02647	0.998	30,462,287	−0.07573	0.943
1976	107,116,759	−0.02108	0.990	35,400,624	−0.06767	0.927
1977	147,774,792	−0.02425	0.994	70,115,890	−0.09753	0.973

[1]Based upon least squares fit of ln*P* on *C*, where *P* = cumulative weight (pounds, heads-off) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, *C* = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, ln(*c*) = intercept, and *d* = slope; all slopes, *d*, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.

level) in most years for all species on the south Atlantic coast than on the Gulf coast, indicating that the differences in value per shrimp among the various size categories were greater on the Gulf coast than on the south Atlantic coast (Tables 1-3; Fig. 3-5).

Annual Cumulative Landings by Size Category

Size composition of reported annual landings also was characterized with a simple linear function. First we calculated the cumulative weight, *P*, of landings in each of the same seven size categories for each year. Landings were cumulated starting with the size category of smallest shrimp (highest count, ≥68) and continuing toward the size category of largest shrimp (lowest count, 15-20).

The following exponential model described the relationship between P_i and C_i for each year for the Gulf coast:

$$\widehat{P_i} = ce^{dC_i}$$

where P_i = cumulative weight of landings in the *i*th size category.

A logarithmic transformation converted the exponential model to a simple linear function used to estimate parameters *c* and *d* of the model (Tables 5-7) by least squares.

Lower limits of the size categories were used for the same reasons described in the preceding section. Pieces and the <15 category were excluded from the calculations. The magnitude of the constant, *c*, was influenced by use of lower limits of size categories in fitting the model and by exclusion of pieces from the calculations. The slope, *d*, of the logarithmic form of the exponential model was of greater interest as a simple index characterizing the size composition of the landings.

The model was modified for the south Atlantic coast because of generally small percentages of landings of any of the three species in the 15-20 size category (≤7.9 percent in all years except 1963 in which it was 14.6 percent for pink shrimp only). Both the 15-20 size category as well as the <15 size category were excluded in fitting the model for all species and years. No lines were fitted for pink shrimp for 1967-70, because no landings of pink

Table 6.—Relationship between transformed cumulative weight of landings, ln*P*, and size category, *C*, for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

	Gulf coast			South Atlantic coast		
Year	c[1]	d[1]	Coefficient of determination r^2	c	d	Coefficient of determination r^2
1961	54,114,893	−0.04692	0.981	3,068,072	−0.04078	0.939
1962	69,840,177	−0.05926	0.979	3,524,397	−0.03975	0.957
1963	58,694,114	−0.04535	0.981	1,078,509	−0.05276	0.972
1964	71,589,574	−0.04847	0.969	9,149,959	−0.07824	0.905
1965	74,243,441	−0.05204	0.972	31,636,434	−0.11857	0.842
1966	47,649,372	−0.04669	0.959	14,266,005	−0.12550	0.708
1967	47,784,888	−0.05516	0.945	—[3]	—[3]	—[3]
1968	59,293,485	−0.05938	0.953	—	—	—
1969	48,201,948	−0.05472	0.927	—	—	—
1970	40,405,643	−0.04372	0.947	—	—	—
1971	38,623,444	−0.05379	0.924	4,251,915	−0.04470	0.839
1972	51,004,274	−0.06260	0.915	1,862,295	−0.04814	0.907
1973	61,719,470	−0.05720	0.890	3,299,099	−0.04517	0.896
1974	58,886,946	−0.05842	0.909	3,863,484	−0.03556	0.681
1975	49,471,139	−0.05307	0.895	3,154,498	−0.03136	0.739
1976	46,045,473	−0.05435	0.897	3,428,385	−0.03827	0.785
1977	41,649,920	−0.04337	0.878	1,302,219	−0.04080	0.928

[1]Based upon least squares fit of ln$P$ on C; where P = cumulative weight (pounds, heads-off) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, ln(c) = intercept, and d = slope; all slopes, d, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.
[3]There were no reported landings in the ≥68 size category in 1967-70, so no lines were fitted.

Table 7.—Relationship between transformed cumulative weight of landings, ln*P*, and size category, *C*, for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

	Gulf coast			South Atlantic coast		
Year	c[1]	d[1]	Coefficient of determination r^2	c	d	Coefficient of determination r^2
1961	26,391,961	−0.03704	0.996	32,298,133	−0.06215	0.994
1962	37,142,410	−0.02682	0.986	33,364,399	−0.06085	0.987
1963	90,903,585	−0.03438	0.978	26,589,315	−0.07628	0.992
1964	78,314,239	−0.03671	0.999	25,593,014	−0.07193	0.993
1965	48,293,136	−0.02684	0.999	86,645,878	−0.08607	0.967
1966	45,934,177	−0.02764	0.978	22,302,738	−0.06073	0.998
1967	36,665,983	−0.03188	0.993	109,842,711	−0.11446	0.982
1968	47,651,754	−0.02885	0.996	144,705,326	−0.10421	0.953
1969	69,087,889	−0.02816	0.996	66,246,289	−0.07255	0.972
1970	67,461,660	−0.02916	0.989	53,691,218	−0.08399	0.996
1971	61,811,501	−0.02715	0.997	53,366,833	−0.06183	0.975
1972	51,489,064	−0.02412	0.993	44,105,718	−0.05776	0.972
1973	48,858,553	−0.02242	0.994	49,275,620	−0.05817	0.963
1974	39,538,285	−0.02173	0.985	37,743,733	−0.06375	0.993
1975	35,271,647	−0.01973	0.985	41,466,648	−0.05900	0.977
1976	50,649,504	−0.02457	0.989	29,014,318	−0.04839	0.978
1977	64,385,564	−0.02235	0.993	28,550,928	−0.11271	0.998

[1]Based upon least squares fit of ln$P$ on C, where P = cumulative weight (pounds, heads-off) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, ln(c) = intercept, and d = slope; all slopes, d, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.

shrimp were reported in the ≥68 category in those years. Thus, the least squares fit of ln$P$ on C for south Atlantic coast landings was based upon only six size categories instead of seven. Because estimates of parameters c and d for all species on the south Atlantic coast were based on fewer data points than those for the Gulf coast, comparisons between south Atlantic and Gulf coasts with regard to parameters c and d were not strictly valid. Elimination of the 15-20 size category from the model for the south Atlantic coast probably decreased (increased the absolute value) the slopes, d, for landings from the south Atlantic coast. The lack of landings in the <15 size category and the paucity of landings in the 15-20 size category on the south Atlantic coast could have reflected limited availability to the fishery of shrimp in these size categories (e.g., they may have been present only on untrawlable grounds) or lower abundance of larger shrimp due to higher total mortality or attainment of smaller maximum sizes in colder waters (McCoy, 1972).

Time trends in d are shown in Figures 6-8. There were significant upward trends in d (Table 8; Fig. 6, 8) for brown and white shrimp landings from the Gulf coast, indicating that the size of shrimp in the reported landings decreased from 1961 to 1977. Annual values of d for pink shrimp on the Gulf coast were lower than those for brown and white shrimp (Tables 5-7; Fig. 6-8), but there was no significant trend in d with time for pink shrimp (Table 8; Fig. 7). Annual levels of d for brown, pink, and white shrimp fluctuated widely on the south Atlantic coast (Tables 5-7; Fig. 6-8). In addition, the low level of d for brown and white shrimp landings on the south Atlantic coast in 1967 may have indicated low recruitment in that year.

Annual Cumulative Ex-vessel Value of Landings by Size Category

Ex-vessel value composition of the reported annual landings also was characterized with a simple linear function. First we calculated ex-vessel value of landings in each of the seven size categories for each year. Ex-vessel value of landings was cumulated to obtain D, starting with the size category of smallest shrimp and continuing toward the size category of largest shrimp.

Table 8.—Trends in slopes, *d*, of the least squares fit of transformed cumulative weight of landings, ln*P*, on size category, *C*, for reported annual landings of brown, pink, and white shrimp from the Gulf coast, 1961-77 (based on data from Tables 5-7)[1].

Gulf coast trend[2]	Brown shrimp	Pink shrimp	White shrimp
Intercept	−0.0826	−0.0385	−0.0840
Slope	0.0008*	−0.0002	0.0008*
Coefficient of determination	0.574	0.030	0.658

[1]Asterisk indicates that the slope of the trend (i.e., the change in slope, d, per year) was significantly different from zero at the 95 percent level of confidence. No trend was determined for brown, pink, and white shrimp from the south Atlantic coast because d fluctuated widely (see Tables 5-7; Fig. 6-8).
[2]Represents the least squares fit of d on x, where x is the last two digits of each year, 1961-77.

The following exponential model described the relationship between D_i and C_i for each year for the Gulf coast:

$$\widehat{D_i} = ge^{hC_i}$$

where D_i = cumulative ex-vessel value of landings in the ith size category.

A logarithmic transformation converted the exponential model to a simple linear function used to estimate parameters g and h of the model (Tables 9-11) by least squares.

Table 9.—Relationship between transformed cumulative ex-vessel value of landings, $\ln D$, and size category, C, for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

	Gulf coast			South Atlantic coast		
Year	g^1	h^1	Coefficient of determination r^2	g	h	Coefficient of determination r^2
1961	47,080,525	−0.05345	0.979	7,715,640	−0.09857	0.993
1962	46,878,514	−0.03855	0.986	36,185,896	−0.08446	0.985
1963	62,076,000	−0.05310	0.984	35,530,783	−0.11173	0.979
1964	47,277,261	−0.05059	0.998	49,161,433	−0.12788	0.991
1965	68,438,083	−0.04422	0.997	63,686,935	−0.11870	0.945
1966	89,200,749	−0.04378	0.985	84,558,994	−0.10908	0.973
1967	125,051,974	−0.04780	0.983	531,843,589	−0.19137	0.873
1968	113,289,834	−0.04555	0.988	55,344,619	−0.12619	0.995
1969	87,904,363	−0.03958	0.994	92,952,577	−0.12188	0.978
1970	108,192,218	−0.04522	0.984	48,831,199	−0.11367	0.996
1971	168,095,025	−0.04774	0.989	66,072,950	−0.09933	0.981
1972	213,387,432	−0.04864	0.988	60,647,562	−0.09803	0.974
1973	152,426,032	−0.03737	0.995	47,656,996	−0.09306	0.961
1974	125,700,167	−0.04586	0.965	46,414,850	−0.07837	0.947
1975	212,822,704	−0.04785	0.997	74,525,358	−0.08940	0.957
1976	276,970,068	−0.04057	0.988	96,970,755	−0.08276	0.947
1977	337,761,303	−0.04110	0.992	227,206,533	−0.11582	0.980

[1]Based upon least squares fit of $\ln D$ on C, where D = cumulative ex-vessel value (dollars) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, $\ln(g)$ = intercept, and h = slope; all slopes, h, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.

Table 10.—Relationship between transformed cumulative ex-vessel value of landings, $\ln D$, and size category, C, for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

	Gulf coast			South Atlantic coast		
Year	g^1	h^1	Coefficient of determination r^2	g	h	Coefficient of determination r^2
1961	38,125,732	−0.06251	0.979	1,694,317	−0.05198	0.950
1962	67,180,259	−0.07244	0.978	2,386,599	−0.05133	0.976
1963	48,048,429	−0.06214	0.983	670,273	−0.06557	0.976
1964	56,497,107	−0.06592	0.966	5,800,995	−0.08810	0.929
1965	60,146,872	−0.06612	0.972	21,207,384	−0.13162	0.839
1966	41,546,756	−0.05760	0.966	11,513,260	−0.13647	0.720
1967	45,853,404	−0.06826	0.955	—	—[3]	—[3]
1968	61,801,612	−0.07538	0.968	—	—	—
1969	55,026,751	−0.06969	0.944	—	—	—
1970	44,129,983	−0.05965	0.962	—	—	—
1971	55,028,401	−0.07531	0.938	4,076,992	−0.05217	0.857
1972	90,826,350	−0.08261	0.939	2,102,820	−0.05944	0.921
1973	117,200,887	−0.07131	0.916	4,786,404	−0.05066	0.905
1974	95,299,965	−0.07356	0.951	3,495,825	−0.03870	0.690
1975	115,555,328	−0.07002	0.901	4,298,557	−0.03466	0.755
1976	152,164,084	−0.07334	0.925	8,053,844	−0.04959	0.793
1977	102,679,187	−0.05706	0.921	2,751,014	−0.05192	0.959

[1]Based upon least squares fit of $\ln D$ on C, where D = cumulative ex-vessel value (dollars) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, $\ln(g)$ = intercept, and h = slope; all slopes, h, were significantly different from zero at the 99 percent level of confidence, except those for the south Atlantic coast for the years 1965, 1966, 1974, 1975, and 1976, which were significantly different from zero at the 95 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.
[3]There were no reported landings in the ≥68 size in the years 1967-70, so no lines were fitted.

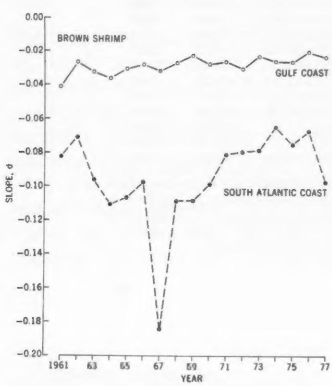

Figure 6.—Variations in slope, d, of the least squares fit of transformed cumulative weight of landings, $\ln P$, on size category, C, for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 5).

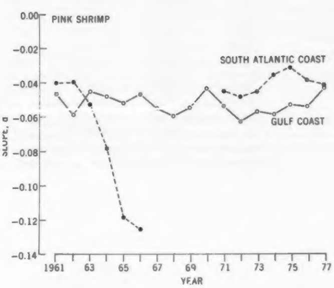

Figure 7.—Variations in slope, d, of the least squares fit of transformed cumulative weight of landings, $\ln P$, on size category, C, for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 6).

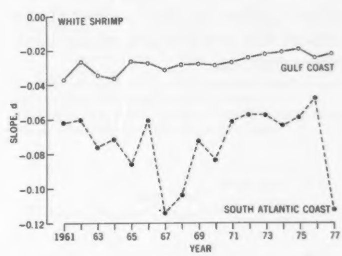

Figure 8.—Variations in slope, d, of the least squares fit of transformed cumulative weight of landings, $\ln P$, on size category, C, for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 7).

We used lower limits of the size categories as in the preceding sections and excluded pieces and the <15 size category. The magnitude of the constant g was influenced by use of lower limits of size categories in fitting the model and by exclusion of pieces. The slope, h, of the logarithmic form of the exponential model was of greater interest as a simple index characterizing the ex-vessel value composition of the landings.

The model was modified for the south Atlantic coast, as in the preceding section, to make the analyses comparable with those for size composition of the landings (Tables 5-7; Fig. 6-8). Neither the 15-20 size category nor the

<15 size category were included in fitting the model for all species and years. No lines were fitted for pink shrimp for 1967-70. Thus, the least squares fit of ln$D$ on C for south Atlantic coast landings was based upon only six size categories instead of seven. Because estimates of parameters g and h for all species on the south Atlantic coast were based on fewer data points than those for the Gulf coast, comparisons between south Atlantic and Gulf coasts with regard to parameters g and h were not strictly valid. Elimination of the 15-20 size category from the model for the south Atlantic coast probably decreased the slopes, g, for ex-vessel value of landings.

There were no significant trends in h with time for brown, pink, and white shrimp from the Gulf coast, but annual levels of h for pink shrimp on the Gulf coast were lower than those for brown and white shrimp (Tables 9-11; Fig. 9-11). Annual levels of h for brown, pink, and white shrimp fluctuated widely on the south Atlantic coast. For this reason, no trend lines were fitted by least squares for the south Atlantic coast. The low level of h for brown and white shrimp landings on the south Atlantic coast in 1967 reflected the unusual size composition of the landings in that year.

Simulations

The models described above provided an opportunity for simulating the results of predictable changes in parameters. Our predictions were based upon the assumption that the observed trends would continue; therefore, we confined them to the Gulf coast landings, which far exceeded those of the south Atlantic coast and which showed greater stability in size composition apart from significant trends (Tables 5-8; Fig. 6-8).

Though the Gulf coast landings of brown, pink, and white shrimp exhibited significant trends in b (Table 4; Fig. 3-5) and those of brown and white shrimp exhibited significant trends in d (Table 8; Fig. 6-8), there were no significant trends in h (Tables 9-11; Fig. 9-11). The greater increase in ex-vessel value of larger shrimp as compared with that for smaller shrimp

Table 11.—Relationship between transformed cumulative ex-vessel value of landings, ln*D*, and size category, *C*, for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and unpublished data)[2].

	Gulf coast			South Atlantic coast		
Year	g^1	h^1	Coefficient of determination r^2	g	h	Coefficient of determination r^2
1961	17,728,428	−0.04636	0.998	25,397,467	−0.7477	0.992
1962	27,391,683	−0.03754	0.996	31,865,357	−0.07449	0.993
1963	50,210,765	−0.05136	0.991	18,208,335	−0.08751	0.995
1964	49,753,929	−0.04905	0.998	22,481,650	−0.08737	0.996
1965	30,516,559	−0.03800	0.997	77,685,563	−0.10172	0.973
1966	36,838,351	−0.03767	0.990	24,958,375	−0.07646	0.998
1967	30,708,806	−0.04659	0.986	116,815,929	−0.13054	0.986
1968	45,121,527	−0.04386	0.993	202,627,525	−0.12376	0.963
1969	69,455,721	−0.04388	0.994	89,364,136	−0.08820	0.975
1970	63,852,737	−0.04721	0.983	70,426,488	−0.10357	0.998
1971	80,572,665	−0.04800	0.996	88,673,354	−0.08186	0.978
1972	71,845,605	−0.03980	0.986	71,083,088	−0.07339	0.985
1973	90,556,090	−0.03424	0.994	126,244,366	−0.07417	0.965
1974	54,060,265	−0.03703	0.966	68,411,398	−0.08182	0.997
1975	74,140,315	−0.03743	0.977	125,361,234	−0.07678	0.984
1976	142,696,421	−0.04389	0.982	97,558,231	−0.06779	0.989
1977	141,109,960	−0.03838	0.984	99,794,138	−0.13064	0.999

[1]Based upon least squares fit of ln$D$ on C, where D = cumulative ex-vessel value (dollars) of annual landings in each of seven size categories for Gulf coast and six size categories for south Atlantic coast, C = lower limit of each of the seven size categories for Gulf coast and the six size categories for south Atlantic coast, ln(g) = intercept, and h = slope; all slopes, h, were significantly different from zero at the 99 percent level of confidence.
[2]Data for 1977 were obtained from NMFS computer printouts.

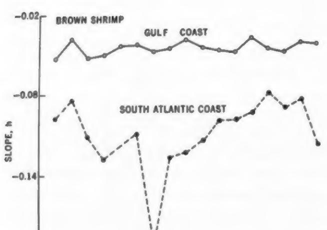

Figure 9.—Variations in slope, h, of the least squares fit of transformed cumulative ex-vessel value of landings, ln$D$, on size category, C, for reported annual landings of brown shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 9).

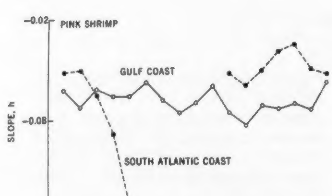

Figure 10.—Variations in slope, h, of the least squares fit of transformed cumulative ex-vessel value of landings, ln$D$, on size category, C, for reported annual landings of pink shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 10).

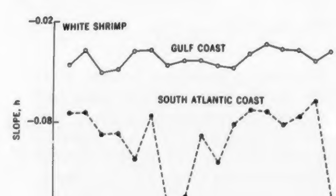

Figure 11.—Variations in slope, h, of the least squares fit of transformed cumulative ex-vessel value of landings, ln$D$, on size category, C, for reported annual landings of white shrimp from Gulf and south Atlantic coasts, 1961-77 (based on data from Table 11).

apparently compensated the decrease in size of shrimp in the landings, because the ex-vessel value composition of the landings remained unchanged apart from year to year fluctuations. Based upon these findings, we would expect the observed trends to continue and the ex-vessel value composition of the Gulf landings to remain stable for a few more years.

We also conducted simulations to estimate what the ex-vessel value per pound of past annual landings of shrimp of each species would have been for various levels of b, to explore the possible consequences of reversing the past trends toward decreasing size of shrimp in the landings. Because there was a significant inverse relationship between $\ln(a)$ and b, as shown by least squares analysis (Table 12), we were able to estimate a for a range of levels of b, to generate parameters for the model,

$$\widehat{V_i} = ae^{bC_i}.$$

We then calculated the corresponding ex-vessel value per pound by size category from the simulated V_i. We used the ex-vessel value per pound obtained for the 15-20 size category as a minimum ex-vessel value per pound for the <15 size category. This provided a conservative estimate of the ex-vessel value per pound for the <15 size category. We then multiplied ex-vessel value per pound in each size category by the observed pounds in each size category for 1961-77. The resulting values were summed over size categories to simulate annual ex-vessel value of shrimp landings for each year. The simulated annual ex-vessel value was then divided by the annual pounds landed (Fig. 1) to obtain simulated annual average ex-vessel value per pound. Simulated annual average ex-vessel value per pound was plotted against d (Fig. 12-14) for each species and year, and straight lines were fitted by least squares (Table 13). It was obvious that an increase in size of shrimp in the landings, as indicated by a decrease in d, coupled with a decrease in b, would result in a dramatic increase in the annual average ex-vessel value per pound for shrimp landings from the Gulf coast (Fig. 12-14). It was also obvious that changes in b produced greater changes in simulated annual average ex-vessel value per pound than equivalent changes in d. Thus the price spread among different size categories had a greater influence than changes in size composition on simulated annual average ex-vessel value per pound. Over the range in d, the change in annual average ex-vessel value per pound was slight at the higher levels of b. As b decreased, there was a greater change in annual average ex-vessel value per pound over the range in d. Because total landings also depend upon recruitment each year (Christmas and Etzold, 1977), the simulated annual ex-vessel value per pound can be used

Table 12.—Least squares fit of ln(a) on *b* for reported annual landings of brown, pink, and white shrimp from the Gulf coast 1961-77 (based on data from Tables 1-3)[1].

Gulf coast	Brown shrimp	Pink shrimp	White shrimp
Intercept	−6.8591	−6.5868	−6.0833
Slope	−98.069*	−95.480*	−84.875*
Coefficient of determination	0.551	0.483	0.454

[1]Asterisk indicates that the slope was significantly different from zero at the 95 percent level of confidence.

Table 13.—Least squares fit of simulated annual average ex-vessel value per pound on *d* for brown, pink, and white shrimp from the Gulf coast, 1961-77 (based on data from Fig. 1 and Tables 1-3, 5-7, 12)[1].

b[2]		Brown shrimp	Pink shrimp	White shrimp
	Intercept	0.3238	0.4516	0.4183
−0.04	Slope	−2.571*	−1.028*	−3.100*
	Coefficient of determination	0.964	0.361	0.923
	Intercept	0.5390	0.7741	0.6405
−0.05	Slope	−7.643*	−3.236*	−7.202*
	Coefficient of determination	0.944	0.342	0.774
	Intercept	0.9269	1.3480	1.0262
−0.06	Slope	−19.336*	−8.378*	−14.792*
	Coefficient of determination	0.918	0.332	0.646
	Intercept	1.6450	2.3781	1.7129
−0.07	Slope	−45.648*	−20.038*	−28.716*
	Coefficient of determination	0.892	0.330	0.540

[1]Asterisk indicates that the slope was significantly different from zero at the 95 percent level of confidence.
[2]The levels of b chosen for the simulation encompass as well as extend the observed range (see Tables 1-3).

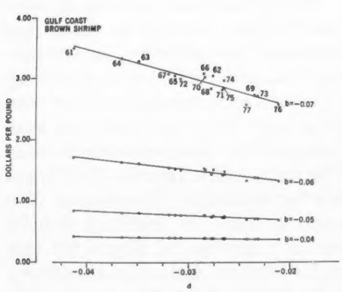

Figure 12.—Simulated annual average ex-vessel value (dollars) per pound (heads-off) of brown shrimp from the Gulf coast at various levels of b over the range of d (based on data from Fig. 1 and Tables 1, 5, 12).

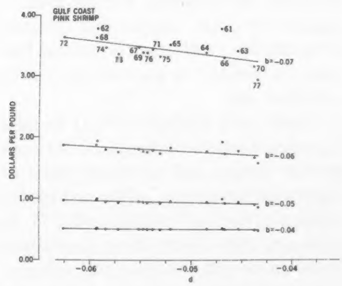

Figure 13.—Simulated annual average ex-vessel value (dollars) per pound (heads-off) of pink shrimp from the Gulf coast at various levels of b over the range of d (based on data from Fig. 1 and Tables 2, 6, 12).

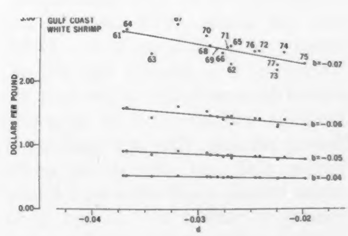

Figure 14.—Simulated annual average ex-vessel value (dollars) per pound (heads-off) of white shrimp from the Gulf coast at various levels of b over the range of d (based on data from Fig. 1 and Tables 3, 7, 12).

as a multiplier for determining annual ex-vessel value for a given weight of landings of a given size composition and for various levels of b.

There was no significant correlation between $\ln(c)$ and d (Tables 5-7), indicating that size composition of the landings was not the major factor affecting the weight of the annual landings. Such a lack of correlation would be expected if another factor (e.g., recruitment) played a larger role in determining variations in weight of shrimp landed in a given year.

Discussion

The extent to which the inclusion of unreported catches would change our results and conclusions cannot be determined. Because reported annual landings of shrimp were not equivalent to the total annual catches of shrimp, the size and ex-vessel value composition of these landings were not necessarily identical to the size and ex-vessel value composition of the total annual catches of a given species in a given coastal area and year. Unknown portions of the total annual catches were not reported; e.g., catches by foreign fishing craft, shrimp discarded because they did not meet minimum size limits or for other reasons, landings by recreational fishermen, and landings sold directly to the consumer. The proportion of the total annual catch not reported as landings was unknown.

There was a significant decrease in size of brown and white shrimp in the landings from the Gulf coast during 1961-77. Fishing effort has increased substantially on the Gulf coast (Christmas and Etzold, 1977; Caillouet and Patella, 1978; Caillouet et al., 1979). Therefore, it is possible that the observed decrease in size of shrimp in the landings was an effect of increased fishing pressure. Reported landings of brown, pink, and white shrimp on the south Atlantic coast either were totally lacking in shrimp of <15 and 15-20 count or contained only small percentages of these size categories, and the size composition of the landings fluctuated widely from year to year.

The range in ex-vessel value per shrimp among the various size categories increased during 1961-77 for all three species on both coasts. Although the annual ex-vessel value of the brown, pink, and white shrimp landings on the Gulf coast increased as the landings increased, the ex-vessel value composition of the landings did not change significantly from year to year. A greater proportion of the ex-vessel value of Gulf landings of brown and white shrimp was represented by shrimp of smaller sizes, compared with the south Atlantic coast landings of the two species. A greater proportion of the ex-vessel value of Gulf landings of pink shrimp was represented by shrimp of larger sizes, compared with Gulf landings of brown and white shrimp. The ex-vessel value composition of brown, pink, and white shrimp landings on the south Atlantic coast fluctuated widely from year to year.

For the most part, small or juvenile shrimp were harvested inshore or nearshore, and larger shrimp (subadults and adults) were harvested offshore, as related to their availability inshore or offshore in different phases of their life cycle (Christmas and Etzold, 1977; Caillouet and Patella, 1978). Trends of increase in the range in ex-vessel value per shrimp among size categories probably reflected trends in supply of shrimp vs. demand for shrimp of various sizes in domestic and world markets, but differences in costs of harvesting shrimp inshore (close to ports) vs. offshore (farther from ports) as well as other factors also may have affected the ex-vessel price spread. Further investigations of costs, supply and demand relationships, and other economic factors are needed to explain the trends we observed.

Gunter and McGraw (1973) found a significant positive correlation between annual weight and ex-vessel value of combined landings of white and brown shrimp on the Gulf coast for 1902-71. In contrast, they observed no correlation between weight and ex-vessel value of combined landings of white and brown shrimp on the south Atlantic coast. They suggested that the south Atlantic coast shrimp stocks had been fished to capacity since the 1920's when production limits seemed to have been reached. Thus, the ex-vessel value of the landings continued to increase while the weight of landings did not. Moreover, they suggested that production of Gulf shrimp would reach an upper limit in the future if fishing continued at a high level, so that Gulf landings and ex-vessel value of the landings would no longer show a correlation, assuming that ex-vessel value of the landings continued to increase.

We have characterized and described ex-vessel value per shrimp by size category, size composition, and ex-vessel value composition of the reported annual landings of brown, pink, and white shrimp on Gulf and south Atlantic coasts. Similar analyses, including additional landings statistics that become available, should be of particular use as one means of monitoring the effects of changes in shrimp fishery management that may be brought about under the Fishery Conservation and Management Act of 1976. Finally, our analyses suggest that the ex-vessel value of a given weight of landings could be greatly increased (Fig. 12-14), if the past trends toward decreasing size of shrimp in the landings could be reversed while the trends in ex-vessel value per shrimp continued. Balanced against this must be a consideration of what management actions could be used to increase the total weight and total value of annual landings.

Acknowledgments

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Relationship Between Ex-vessel Value and Size Composition of Annual Landings of Shrimp From the Gulf and South Atlantic Coasts

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ABSTRACT—The relationship between ex-vessel value and size (number of shrimp per pound, heads-off) composition of annual landings of brown shrimp, Penaeus aztecus, *pink shrimp,* P. duorarum, *and white shrimp,* P. setiferus, *from the Gulf and south Atlantic coasts of the United States was determined. Average annual ex-vessel value per pound, expressed in dollar units based upon 1975 and 1977, was used to compare the landings from the two coasts. Regional differences in price structure and size composition of the annual landings played large roles in determining the ex-vessel value of a given weight of landings. The average annual ex-vessel value per pound for brown and white shrimp was higher on the south Atlantic coast than on the Gulf coast. For pink shrimp, the average annual ex-vessel value per pound was lower on the south Atlantic coast than on the Gulf coast.*

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Introduction

Caillouet and Patella (1978) and Caillouet et al. (1979) compared the commercial shrimp fisheries of the states bordering the Gulf of Mexico using average annual ex-vessel value per pound for reported annual catches of brown shrimp, *Penaeus aztecus*, pink shrimp, *P. duorarum*, and white shrimp, *P. setiferus*. They compared these fisheries because the fisheries are regulated by different state laws (Christmas and Etzold, 1977), resulting in different harvesting strategies that affect the size distributions and therefore the value of shrimp harvested within each state.

For 1959-75, Caillouet and Patella (1978) and Caillouet et al. (1979) showed that the average annual ex-vessel value per pound (expressed in dollar units based on the year 1975) for reported annual catches ranged from a high of $2.22 for brown shrimp in Texas to a low of $1.36 for the same species in Louisiana (Table 1). The average annual ex-vessel value per pound for pink and white shrimp fell within this range. Differences among states in average annual ex-vessel value per pound were attributed primarily to differences in size composition of the catches. Large shrimp commanded higher prices than did small shrimp on the market, so when a large proportion of the reported catch was made up of small shrimp (e.g., in Louisiana), the ex-vessel value per pound for that catch was lower than that of a catch of equal weight in which a smaller proportion was made up of small shrimp (e.g., in Texas).

In this paper we employ analyses similar to those used by Caillouet and Patella (1978) and Caillouet et al. (1979) to compare the average annual ex-vessel value per pound for reported annual landings of brown, pink, and white shrimp from Gulf and south Atlantic coasts of the United States for 1961-77. Shrimp fisheries of the Gulf coast of the United States have been described by Christmas and Etzold (1977), and those of the south Atlantic coast of the United States have been described by Calder et al. (1974). Gunter and McGraw (1973) have investigated correlations among the annual landings of brown and white shrimp from the Gulf and south Atlantic coasts.

Table 1.—Average annual ex-vessel value per pound (heads-off; expressed in 1975 dollar units) of reported annual catches of brown, pink, and white shrimp from five regions of the U.S. coast of the Gulf of Mexico, 1959-75.[1]

Region	Brown shrimp ($/lb)	Pink shrimp ($/lb)	White shrimp ($/lb)
Texas coast	2.22	2.07	—[2]
Mississippi River to Texas	1.36	1.75	—
Pensacola to Mississippi River	1.55	1.97	—
Appalachicola	—	—	1.52
Sanibel to Tortugas	—	—	1.56

[1]Adapted from Caillouet and Patella (1978) and Caillouet et al. (1979).
[2]Not determined. Calculations were made only for the dominant species in each region.

Description of Data

Landings statistics for 1961-69 were obtained from the U.S. Fish and Wildlife Service (1962-71), those for 1970-76 were obtained from the National Marine Fisheries Service (1971-78), and unpublished computer printouts of landings statistics for 1977 were obtained from Richard L. Schween[1]. Reported annual landings were expressed in pounds (heads-off), and ex-vessel value in dollars, by year (1961-77), coastal area (Gulf and south Atlantic coasts), species (brown, pink, and white shrimp), and size category, commonly referred to as "count" (number of shrimp per pound, heads-off, including the categories <15, 15-20, 21-25, 26-30, 31-40, 41-50, 51-67, ≥68, and "pieces"). These landings constituted combined inshore and offshore catches landed by domestic fishermen at domestic ports in each coastal area, for shrimping trips completed within each year.

Analytical Methods and Results

Using data for 1975 and 1977, we first divided dollars by pounds in each

[1]Richard L. Schween, Resource Statistics Division, National Marine Fisheries Service, NOAA, Washington, D.C., pers. commun. January 1979.

size category to obtain the annual price structure of the landings (i.e., ex-vessel value per pound by size category) for each species and both coasts (Table 2). We chose dollar units for 1975 so that our results could be compared with those of Caillouet and Patella (1978) and Caillouet et al. (1979), and we chose dollar units for 1977 because 1977 was the latest year for which data were available. Using the annual price structures for 1975 and 1977, we then multiplied ex-vessel value per pound by the reported pounds landed in each size category, for each species, both coastal areas, and the years 1961-77. Summation over size categories provided estimates of annual ex-vessel value (both in 1975 and 1977 units) of the reported annual landings by coastal area, species, and year.

A straight line was fitted by least squares through the origin and through data points representing estimated annual ex-vessel value and reported annual landings, one line for each combination of coastal area, species, and dollar unit basis (1975 and 1977). The slope of each line represented average annual ex-vessel value per pound, based on the entire time series, 1961-77 (Table 3; Fig. 1-12). Coefficients of determination (r^2) were also calculated for each fitted line.

Unlike the Gulf coast, the south Atlantic coast contained no landings in the <15 size category for most years and species (Tables 4-9). For this reason, dollars per pound in the <15 size category could not be calculated for

Table 2.—Price structure (ex-vessel value per pound, heads-off, by size category) of reported annual landings of brown, pink, and white shrimp from Gulf and south Atlantic coasts of the United States in 1975 and 1977 (based on National Marine Fisheries Service, 1976, and Richard L. Schween, pers. commun., January 1979).[1]

Size category (count) No./lb[2]	Brown shrimp				Pink shrimp				White shrimp			
	Gulf coast		S. Atlantic coast		Gulf coast		S. Atlantic coast		Gulf coast		S. Atlantic coast	
	1975 $/lb	1977 $/lb	1975 $/lb	1977 $/lb	1975 $/lb	1977 $/lb	1975 $/lb	1977 $/lb	1975 $/lb	1977 $/lb	1975 $/lb	1977 $/lb
≤15	2.86	4.34	ND[3]	3.65	2.65	3.63	ND	4.27	2.93	4.14	ND	ND
15-20	2.74	3.57	2.52	3.25	2.34	3.47	2.97	3.55	2.85	3.54	2.90	3.03
21-25	2.73	2.88	2.56	2.85	2.19	3.21	2.43	3.11	2.78	2.87	2.81	2.61
26-30	2.50	2.67	2.40	2.65	2.04	2.76	2.34	2.85	2.52	2.56	2.45	2.41
31-40	2.13	2.16	1.98	2.17	1.82	2.36	1.74	2.05	2.12	2.09	2.27	2.18
41-50	1.66	1.62	1.57	1.62	1.46	1.66	1.38	1.59	1.63	1.62	1.72	1.81
51-67	1.32	1.27	1.22	1.31	1.23	1.34	1.22	1.28	1.25	1.27	1.37	1.46
≥68	0.59	0.76	0.98	0.94	0.64	0.96	1.06	1.01	0.68	0.79	0.89	1.04
Pieces	0.88	1.06	ND	ND	0.74	1.40	ND	ND	0.63	0.93	ND	ND

[1]Values in this table were rounded to hundredths, but additional significant digits were carried in calculations described in this paper.
[2]Heads-off.
[3]ND = no data. No landings were reported in the "pieces" category for all three species in 1975 and 1977 on the south Atlantic coast. For all three species in 1975 and 1977, landings were reported in the "pieces" category on the Gulf coast.

Table 3.—Average annual ex-vessel value per pound (heads-off; expressed in 1975 and 1977 dollar units) of reported annual landings of brown, pink, and white shrimp from Gulf and south Atlantic coasts of the United States (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and Richard L. Schween, pers. commun., January 1979).[1]

Region	Brown shrimp		Pink shrimp		White shrimp	
	$/lb (1975 units)	$/lb (1977 units)	$/lb (1975 units)	$/lb (1977 units)	$/lb (1975 units)	$/lb (1977 units)
Gulf coast	1.79 (0.945)	1.98 (0.931)	1.[illegible]9 (0.982)	2.21 (0.967)	1.83 (0.957)	1.97 (0.948)
South Atlantic coast	1.93 (0.936)	2.11 (0.915)	1.45 (0.900)	1.63 (0.834)	2.10 (0.960)	2.08 (0.971)

[1]Coefficients of determination, r^2, are shown in parentheses. For least squares lines through the origin, r^2 was calculated as follows: $r^2 = 1 - (s^2_{reg.}/s^2_{val.})$ where $s^2_{reg.}$ is the variance due to regression, and $s^2_{val.}$ is the variance in ex-vessel value of the reported annual landings.

Table 4.—Percentage of weight (heads-off), by size category, of reported annual landings of brown shrimp from the Gulf coast, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and Richard L. Schween, pers. commun., January 1979).[2]

Year	Number of shrimp per pound							
	<15	15-20	21-25	26-30	31-40	41-50	51-67	≥68
1961	5.2	14.1	12.7	11.8	26.4	10.2	7.2	12.4
1962	4.4	13.7	11.9	8.0	17.1	12.7	8.7	23.5
1963	3.5	14.0	11.3	10.6	25.2	9.7	8.6	17.0
1964	5.2	14.5	13.0	10.0	20.1	9.5	13.7	13.9
1965	2.6	10.1	13.9	10.4	19.1	11.6	12.7	19.6
1966	3.0	10.9	15.1	10.0	20.3	8.4	9.1	23.2
1967	1.5	8.2	13.6	13.2	24.3	8.9	9.8	20.5
1968	1.9	7.8	11.0	10.3	21.9	11.0	11.6	24.5
1969	2.4	10.1	11.4	8.5	15.9	10.5	12.1	29.1
1970	2.1	11.8	13.5	10.3	19.8	7.7	11.9	22.9
1971	2.4	8.9	9.4	9.8	21.2	12.7	9.4	26.2
1972	1.8	8.5	13.2	10.4	23.3	10.2	11.5	21.1
1973	2.5	11.4	8.9	7.9	17.3	11.1	11.1	29.7
1974	1.8	10.9	13.6	10.5	20.3	8.2	8.4	26.2
1975	1.7	10.4	12.2	8.8	18.2	10.8	12.7	25.2
1976	1.5	8.7	9.6	9.1	17.9	8.1	11.4	33.8
1977	0.9	5.2	11.0	9.8	19.2	10.1	14.9	29.0

[1]Rows may not sum to 100 percent due to rounding.
[2]Data for 1977 were obtained from unpublished computer printouts.

Table 5.—Percentage of weight (heads-off), by size category, of reported annual landings of pink shrimp from the Gulf coast, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and Richard L. Schween, pers. commun., January 1979).[2]

Year	Number of shrimp per pound							
	<15	15-20	21-25	26-30	31-40	41-50	51-67	≥68
1961	0.2	4.7	21.5	19.1	25.9	10.7	7.6	10.3
1962	0.3	9.6	11.2	17.1	31.3	16.5	8.7	5.2
1963	0.3	3.7	13.1	14.7	28.7	16.3	12.8	10.4
1964	0.3	6.0	9.2	12.0	30.5	20.0	13.2	8.7
1965	0.5	6.7	11.8	13.1	29.1	18.2	13.5	7.0
1966	1.0	5.0	10.4	12.5	26.3	17.7	18.5	8.7
1967	1.9	6.2	9.9	13.6	27.8	17.2	18.2	5.3
1968	1.0	6.4	14.0	15.1	28.3	14.0	16.9	4.2
1969	1.3	4.6	11.1	14.3	25.5	16.1	21.8	5.2
1970	0.4	4.2	9.6	12.6	25.3	15.2	22.9	9.8
1971	0.8	7.6	13.0	15.1	19.0	16.7	22.6	5.2
1972	0.9	10.4	14.8	13.8	21.1	15.6	20.5	3.1
1973	0.7	5.7	10.0	15.4	25.2	11.3	27.6	4.1
1974	0.7	6.4	12.7	16.0	22.3	14.4	23.7	3.9
1975	0.4	6.9	11.7	13.0	22.2	12.5	28.1	5.1
1976	1.2	8.0	10.4	14.2	21.3	13.3	26.8	4.7
1977	0.8	5.3	7.3	10.2	20.2	14.1	33.4	8.7

[1]Rows may not sum to 100 percent due to rounding.
[2]Data for 1977 were obtained from unpublished computer printouts.

Table 6.—Percentage of weight (heads-off), by size category, of reported annual landings of white shrimp from the Gulf coast, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and Richard L. Schween, pers. commun., January 1979).[2]

Year	Number of shrimp per pound							
	<15	15-20	21-25	26-30	31-40	41-50	51-67	≥68
1961	0.6	12.9	17.2	11.0	17.8	11.0	15.6	13.9
1962	0.4	9.0	9.6	8.6	16.9	11.5	20.2	23.8
1963	0.2	6.5	9.6	12.5	21.9	12.4	20.5	16.5
1964	1.2	14.2	14.6	11.5	20.1	11.3	12.3	14.8
1965	2.4	16.9	10.1	7.6	15.6	10.3	14.1	23.1
1966	2.6	13.0	10.8	7.9	14.3	8.2	22.1	21.0
1967	3.5	18.8	15.7	9.5	15.5	8.1	11.4	17.6
1968	2.6	10.9	13.2	11.1	16.6	8.1	16.5	21.1
1969	1.5	10.5	11.7	11.4	18.9	8.8	14.2	23.0
1970	2.1	12.9	16.4	12.3	15.5	8.1	11.2	21.5
1971	3.1	10.4	13.0	10.6	16.7	9.6	12.9	23.8
1972	3.2	12.2	11.6	9.0	16.6	8.6	11.1	27.8
1973	1.9	8.1	7.1	8.5	19.1	9.0	15.4	30.9
1974	4.0	12.8	12.8	8.6	13.6	6.6	11.2	30.3
1975	2.7	11.5	10.5	8.3	15.0	6.9	10.2	34.9
1976	2.7	9.6	13.7	11.8	15.5	6.8	12.8	27.2
1977	1.6	7.3	11.5	10.8	16.7	7.3	13.7	31.3

[1]Rows may not sum to 100 percent due to rounding.
[2]Data for 1977 were obtained from unpublished computer printouts.

Table 7.—Percentage of weight (heads-off), by size category, of reported annual landings of brown shrimp from the south Atlantic coast, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and Richard L. Schween, pers. commun., January 1979).[2]

	Number of shrimp per pound							
Year	<15	15-20	21-25	26-30	31-40	41-50	51-67	≥68
1961	0.0	4.8	7.7	30.9	31.3	15.0	8.0	2.2
1962	0.0	2.0	9.1	15.8	36.0	20.9	12.3	3.9
1963	0.0	6.5	8.0	17.3	40.4	20.9	5.8	1.3
1964	0.0	5.6	12.1	28.2	40.6	8.5	4.4	0.6
1965	0.2	0.6	6.5	18.0	37.3	26.1	10.6	0.6
1966	0.0	0.1	16.1	22.8	32.4	17.3	10.3	1.0
1967	0.0	6.0	7.1	13.6	42.8	24.0	6.5	[3]0.0
1968	[3]0.0	5.4	19.6	30.8	30.3	8.3	5.0	0.6
1969	0.0	4.7	17.0	16.5	40.4	13.7	7.0	0.6
1970	0.0	5.3	15.0	28.1	34.2	11.2	5.0	1.1
1971	0.0	2.4	17.8	13.9	32.9	20.1	10.6	2.2
1972	0.0	0.7	12.0	16.8	34.8	20.1	13.2	2.4
1973	0.0	0.7	8.1	14.9	38.4	18.1	17.4	2.4
1974	0.0	0.5	2.7	5.6	27.5	43.4	15.1	5.3
1975	0.0	0.7	3.2	10.2	40.3	25.0	17.6	2.9
1976	0.0	0.5	6.4	10.1	30.3	26.5	22.3	4.0
1977	[3]0.0	5.8	11.0	20.6	34.1	20.2	7.2	1.1

[1]Rows may not sum to 100 percent due to rounding.
[2]Data for 1977 were obtained from unpublished computer printouts.
[3]These categories contained small percentages not apparent due to rounding.

Table 8.—Percentage of weight (heads-off), by size category, of reported annual landings of pink shrimp from the south Atlantic coast, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and Richard L. Schween, pers. commun., January 1979).[2]

	Number of shrimp per pound							
Year	<15	15-20	21-25	26-30	31-40	41-50	51-67	≥68
1961	0.0	4.3	2.5	5.2	21.2	27.4	24.9	14.5
1962	0.0	3.6	12.6	9.5	13.9	22.5	23.7	14.2
1963	0.0	14.6	8.0	11.6	19.2	26.1	12.8	7.7
1964	0.0	5.0	7.3	10.7	32.1	20.0	22.7	2.1
1965	0.0	0.0	0.0	0.0	6.6	81.8	11.3	0.4
1966	0.0	0.0	0.1	0.2	0.4	52.8	46.4	0.1
1967	0.0	3.2	0.0	0.0	32.1	64.3	0.4	0.0
1968	0.0	1.8	8.3	1.7	20.5	43.0	24.7	0.0
1969	0.0	1.3	4.6	4.3	20.7	41.7	27.3	0.0
1970	0.0	0.3	1.3	11.5	28.9	46.4	11.6	0.0
1971	0.0	0.0	0.0	2.7	15.9	27.1	43.1	11.2
1972	0.0	0.0	0.0	0.8	22.8	39.0	26.6	10.9
1973	0.0	0.3	0.2	3.5	16.1	38.5	29.2	12.1
1974	0.0	0.1	0.1	[3]0.0	0.1	13.3	71.0	15.2
1975	0.0	0.8	0.7	0.7	4.0	15.7	58.4	19.7
1976	0.0	0.6	0.2	1.9	5.0	26.9	50.8	14.6
1977	0.1	6.8	11.5	2.1	21.2	16.6	29.0	12.7

[1]Rows may not sum to 100 percent due to rounding.
[2]Data for 1977 were obtained from unpublished computer printouts.
[3]These categories contained small percentages not apparent due to rounding.

Table 9.—Percentage of weight (heads-off), by size category, of reported annual landings of white shrimp from the south Atlantic coast, 1961-77[1] (based on U.S. Fish and Wildlife Service, 1962-71, National Marine Fisheries Service, 1971-78, and Richard L. Schween, pers. commun., January 1979).[2]

	Number of shrimp per pound							
Year	<15	15-20	21-25	26-30	31-40	41-50	51-67	≥68
1961	0.0	3.5	20.1	24.3	26.2	12.7	7.5	5.7
1962	[3]0.0	0.8	9.7	21.8	27.5	19.4	14.7	6.0
1963	0.0	4.4	17.8	20.2	28.6	17.1	9.0	2.8
1964	0.0	3.1	22.1	22.3	24.7	13.5	11.0	3.2
1965	0.0	2.6	15.2	18.1	30.4	20.9	11.1	1.7
1966	0.0	1.2	21.0	16.9	29.1	15.5	10.3	6.0
1967	0.0	1.7	17.7	31.6	29.0	14.5	5.0	0.5
1968	0.0	1.3	15.1	29.5	27.1	16.2	10.2	0.7
1969	[3]0.0	0.2	9.0	20.0	33.0	19.4	15.1	3.4
1970	0.0	1.0	23.3	23.0	29.5	14.0	7.3	2.0
1971	0.0	1.4	15.5	16.2	25.7	18.9	17.1	5.3
1972	0.0	0.8	7.5	19.8	28.1	17.1	20.0	6.5
1973	0.0	1.0	8.5	20.0	23.3	20.2	20.8	6.3
1974	0.0	1.4	13.2	21.2	30.3	15.7	13.1	5.2
1975	0.0	0.6	11.4	23.2	25.6	14.1	19.1	6.0
1976	[3]0.0	0.3	10.6	19.4	23.6	14.2	21.9	9.9
1977	0.0	7.9	43.4	24.6	16.1	5.1	2.5	0.4

[1]Rows may not sum to 100 percent due to rounding.
[2]Data for 1977 were obtained from unpublished computer printouts.
[3]These categories contained small percentages not apparent due to rounding.

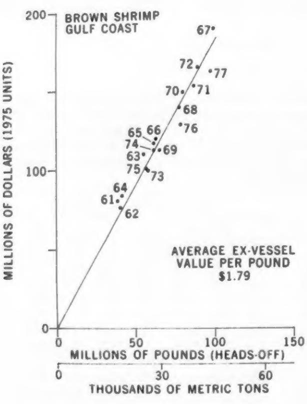

Figure 1.—Relationship between estimated annual ex-vessel value (millions of dollars in 1975 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of brown shrimp from the Gulf coast, 1961-77.

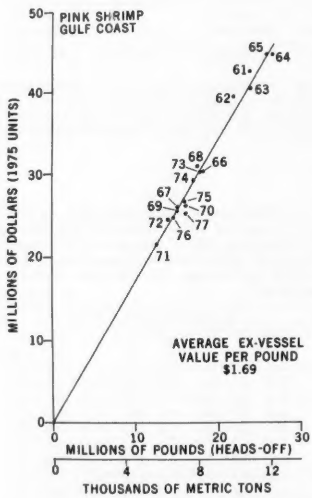

Figure 2.—Relationship between estimated annual ex-vessel value (millions of dollars in 1975 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of pink shrimp from the Gulf coast, 1961-77.

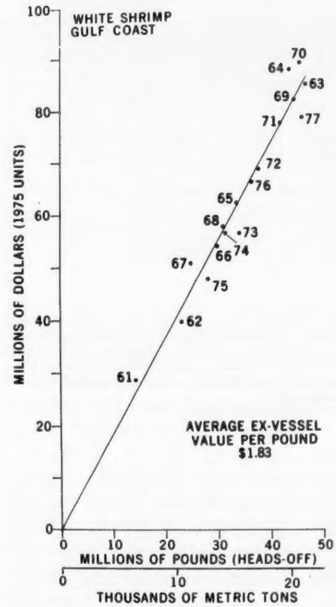

Figure 3.—Relationship between estimated annual ex-vessel value (millions of dollars in 1975 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of white shrimp from the Gulf coast, 1961-77.

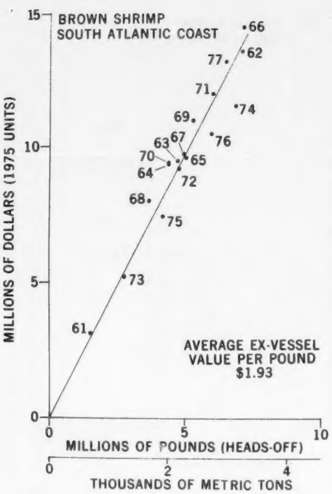

Figure 4.—Relationship between estimated annual ex-vessel value (millions of dollars in 1975 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of brown shrimp from the south Atlantic coast, 1961-77.

brown, pink, and white shrimp in 1975 nor for white shrimp in 1977, for the south Atlantic coast. This was a problem because the <15 size category did contain landings of brown shrimp in 1965, 1968, and 1977, pink shrimp in 1977, and white shrimp in 1962, 1969, and 1976 on the south Atlantic coast, requiring that such landings be included in the estimate of annual ex-vessel value for those species and years. Thus, for the south Atlantic coast, we used dollars per pound calculated for the 15-20 size category as an initial minimum approximation of dollars per pound in the <15 size category for brown, pink, and white shrimp in 1975 and for white shrimp in 1977. In this way, the approximations contributed to the estimates of annual ex-vessel value of the landings for those species and years containing landings in the <15 size category. Then, we fitted a straight line through the origin and through the data points representing estimated annual ex-vessel value and reported annual landings, as described in the preceding paragraph, to obtain estimates of slope (average annual ex-vessel value per pound) and coefficient of determination. Thereafter, we iterated this procedure by $0.01 increments in dollars per pound in the <15 category for brown, pink, and white shrimp in 1975 and for white shrimp in 1977, generating new estimates of annual ex-vessel value and fitting a new line through the origin and data points for each iteration, until the slope of the fitted line increased by $0.01. In all cases, dollars per pound for the <15 size category had to be incremented to unrealistically high

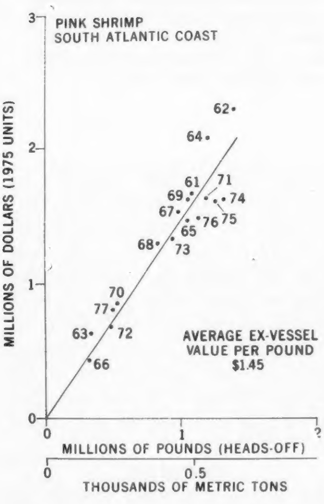

Figure 5.—Relationship between estimated annual ex-vessel value (millions of dollars in 1975 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of pink shrimp from the south Atlantic coast, 1961-77.

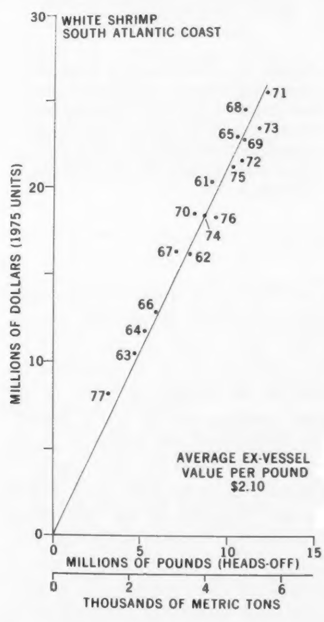

Figure 6.—Relationship between estimated annual ex-vessel value (millions of dollars in 1975 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of white shrimp from the south Atlantic coast, 1961-77.

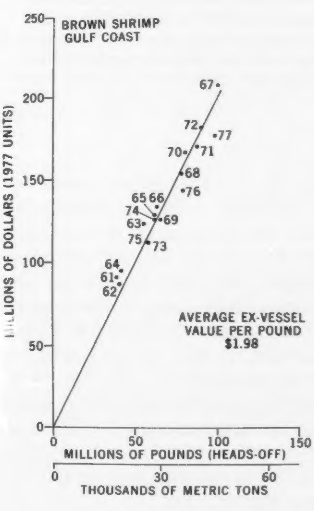

Figure 7.—Relationship between estimated annual ex-vessel value (millions of dollars in 1977 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of brown shrimp from the Gulf coast, 1961-77.

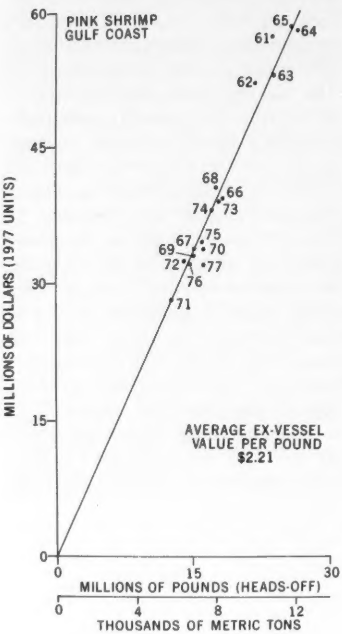

Figure 8.—Relationship between estimated annual ex-vessel value (millions of dollars in 1977 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of pink shrimp from the Gulf coast, 1961-77.

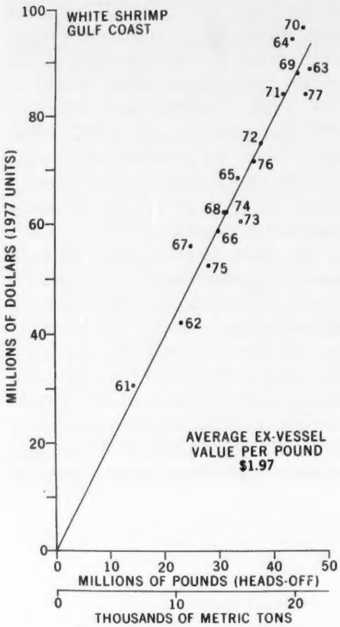

Figure 9.—Relationship between estimated annual ex-vessel value (millions of dollars in 1977 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of white shrimp from the Gulf coast, 1961-77.

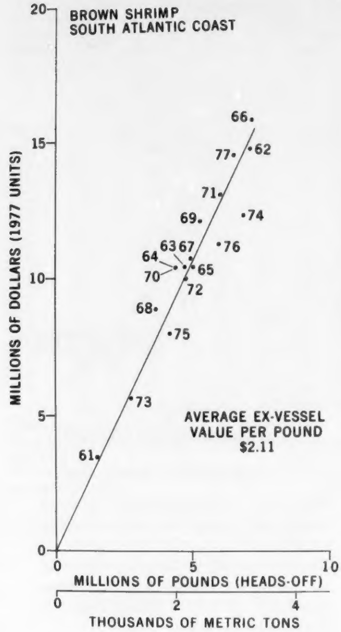

Figure 10.—Relationship between estimated annual ex-vessel value (millions of dollars in 1977 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of brown shrimp from the south Atlantic coast, 1961-77.

values (i.e., ≥$257.00 per pound) before the slope of the line changed by $0.01. Therefore, in the few cases in which the <15 size category contained landings, these landings were too low to cause a $0.01 change in the slope of the least squares line until the dollars per pound for the <15 size category was incremented to levels far above what they possibly could have been. Thus, the slopes calculated with initial approximations of dollars per pound in the <15 size category were considered representative (Table 3).

The size category "pieces" also was used in the estimation of annual ex-vessel value of reported annual landings. Though there were no landings reported as pieces for brown, pink, and white shrimp during 1961-77 on the south Atlantic coast or during 1961-69 on the Gulf coast, some landings were reported as pieces for all three species on the Gulf coast during 1970-77. Thus, there was no contribution by pieces to the weight or value of the annual landings for the south Atlantic coast, and dollars per pound of pieces could be calculated for 1975 and 1977 for all species on the Gulf coast. Pieces were not included in the calculation of percentages shown in Tables 4-9, because it was assumed that the pieces represent all size categories in proportion to their percentage contribution to the landings.

The use of price structures (ex-vessel value per pound by size category, Table 2) for 1975 and 1977 provided comparisons among species and between coastal areas based upon price structures of two recent years. Because price structure was calculated separately for each species and coastal area, any differences we showed among species and between coastal areas, in the slope of the relationship between estimated annual ex-vessel value and weight of reported annual landings (Table 3), were determined by the combined effects of size composition of the landings (Tables 4-9) and the price structure for each species and coastal area (Table 2).

Discussion

For brown and white shrimp, the average annual ex-vessel value per pound was higher on the south Atlantic coast than on the Gulf coast, based both on 1975 and 1977 dollar units (Table 3). This reflected the differences between Gulf and south Atlantic coasts in size composition and price structure of

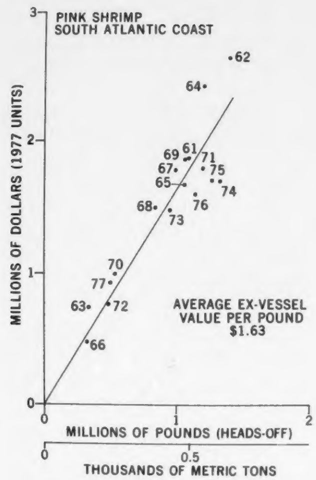

Figure 11.—Relationship between estimated annual ex-vessel value (millions of dollars in 1977 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of pink shrimp from the south Atlantic coast, 1961-77.

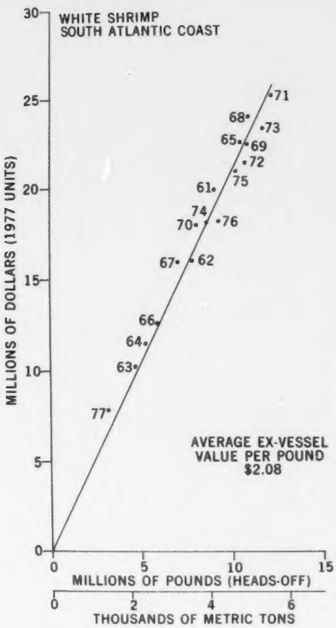

Figure 12.—Relationship between estimated annual ex-vessel value (millions of dollars in 1977 units) and reported annual landings (millions of pounds or thousands of metric tons, heads-off) of white shrimp from the south Atlantic coast, 1961-77.

the annual landings of brown and white shrimp (Tables 2, 4, 6, 7, 9). On the south Atlantic coast, the landings of brown and white shrimp contained larger proportions of intermediate size shrimp than did landings from the Gulf coast. For pink shrimp, the average annual ex-vessel value per pound was lower on the south Atlantic coast than on the Gulf coast (Table 3), reflecting the greater proportion of larger shrimp in the landings from the Gulf coast (Tables 5, 8).

While the average annual ex-vessel value per pound for brown and white shrimp was higher on the south Atlantic coast than on the Gulf coast (Table 3), the combined annual landings of brown, pink, and white shrimp were about 15 times greater on the Gulf coast than on the south Atlantic coast. This, coupled with the fact that the average annual ex-vessel value per pound for pink shrimp was higher on the Gulf coast than on the south Atlantic coast (Table 3), made the total ex-vessel value of the Gulf coast shrimp landings substantially greater than that of the south Atlantic coast shrimp landings.

As expected, due to inflation, the average annual ex-vessel value per pound based upon 1977 dollar units was higher than that based upon 1975 dollar units for all combinations of species and coastal areas except one: White shrimp from the south Atlantic coast (Table 3). In general, there was a larger increase in value per pound for larger shrimp than for smaller shrimp; however, the value per pound decreased slightly in some instances from 1975 to 1977 (Table 2). For white shrimp on the south Atlantic coast, between 1975 and 1977, the ex-vessel value per pound increased only slightly for some size categories and decreased for others (Table 2). Both the total annual landings of white shrimp and the range of variation in these landings on the south Atlantic coast were much smaller than those for white shrimp on the Gulf coast (Fig. 3, 6, 9, 12). For these reasons, the change in price structure of white shrimp on the south Atlantic coast between 1975 and 1977 did not produce an increase in average annual ex-vessel value per pound.

Regional differences in price structure and size composition of annual landings of shrimp play large roles in determining the ex-vessel value of a given weight of landings. Because differences in size composition of the landings reflect regional differences in shrimp laws and harvesting strategies as well as possible differences in shrimp growth and natural mortality (Christmas and Etzold, 1977; McCoy, 1972), it is tempting to speculate that the ex-vessel value per pound of landings could be increased by altering shrimp harvesting strategies to increase the size of shrimp in the landings.

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Sea Turtle Tracked By Satellite

A satellite traditionally used to detect ship movements has successfully tracked the 800-mile odyssey of a sea turtle dubbed "Dianne."

The National Oceanic and Atmospheric Administration (NOAA) said a 212-pound loggerhead was tracked via transmitter from its release point south of Gulfport, Miss., southward around the mouth of the Mississippi River, westward, offshore from Louisiana into Texas, and southward to an area in the Gulf of Mexico offshore from Brownsville, Tex.

After a brief break in transmission, officials of the Commerce Department agency reported, a mystery developed when the signal from the transmitter started anew and inexplicably began moving inland, finally stopping in landlocked Kansas far from Dianne's ocean and rivermouth habitat.

The "mystery" proved to be a fisherman who found the 7-pound transmitter on a beach 30 miles west of Port Arthur, Tex. He took it home to Kansas where he was using the $5,000 device as a doorstop!

The tracking of Dianne lasted from 16 October 1979 to 15 June 1980 when the turtle apparently shed the transmitter. Electronic engineer Robert Timko of NOAA's National Marine Fisheries Service laboratory in Galveston, Tex., called the unusual use of the Nimbus satellite an unqualified success.

"Satellite tracking has great potential because of the inaccessible nature of the animal (turtles)," Timko said. "No other technology is capable of following a wide-ranging mammal over so large an area." He said learning the routes the turtle took will better enable the NMFS to identify feeding, nesting, and mating areas. This information can be used to develop strategies for managing the stock of sea turtles.

The signals from the tracking device attached to Dianne's shell were beamed at 4-day intervals to NASA's Goddard Space Center near Washington, D.C., where they were processed by computer. Satellite tracking of turtles was inspired by a previous experiment with polar bears. The bears were tracked from 60 to 90 days.

A loggerhead, a threatened species, was chosen initially for the project because of its size and availability. However, the success of the experiment prompted the bugging of a smaller Kemp Ridley turtle with a similar satellite transmitter in early June. Signals from the second turtle indicate that it has not moved far from where it was originally tagged off a Mexican beach.

FOUR NMFS LABS GET SOLAR GRANTS

The Northeast Fisheries Center's Woods Hole Laboratory, Woods Hole, Mass., has received a grant of $113,829 from the Department of Energy to install a solar power heating and water heating system. The Grant is one of four awarded to National Marine Fisheries Service laboratories. Other facilities receiving grants are located at Gloucester, Mass.; La Jolla, Calif.; and Narragansett, R.I.

The Woods Hole system, to be completed in 18 months, is expected to provide approximately 18 percent of the building's energy requirements. The project is one of 843 totaling $31 million funded by the Department of Energy.

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